PARTICIPATION AND CONFLICTING OBJECTIVES IN THE ERA OF INTEGRATED WATER RESOURCES MANAGEMENT: A CASE STUDY OF SÃO PAULO, BRAZIL

by

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ABSTRACT

The metropolitan region of São Paulo, Brazil experienced an unprecedented drought between 2013-2015, putting millions of people at risk of water shortages. The impending water crisis brought into question both the reliability of water supplies and the adaptive management capacity of the institutions in charge of the region's water. The problem is not unique to São Paulo. The Integrated Water Resources Management (IWRM) framework is an international effort to promote adaptive governance in water policy, and Brazil is one of the proponents of IWRM's principles of decentralized, integrated, and participatory management capacities to deal with water conflicts. This work examines the technical and non-technical challenges in São Paulo and explores how combining computer models with stakeholder engagement can build water governance. A mixed-method approach is used including interviews, meeting attendance, analysis of technical documents, and quantitative methods with the construction of a mock collaborative model. The objectives are: 1) Examine computer models used for stakeholder engagement in water resources management and characterize the mechanisms that make them effective participatory decision tools; 2) Chronicle and critically examine drought response and water management in São Paulo; 3) Develop a collaborative modeling framework of São Paulo's water system to analyze system performance and propose contingency plans for improved response.

To structure the analysis, Chapter 2 explores the five dimensions of participation and the complexity of creating models that are timely, flexible, transparent, and relevant to the stakeholder engagement process. Chapters 3 and 4 provide different perspectives on São Paulo's water crisis: Chapter 3 explores the institutional challenges, which were exacerbated by a history of increasing water demands in the region, while Chapter 4 is a technical analysis of system performance and alternative drought plans.

São Paulo's drought and the ensuing water allocation process expose the conflicting objectives of the IWRM framework. Furthermore, the analysis of system performance identifies inconsistencies between public statements concerning risks and system vulnerabilities and the actual situation during the drought. Despite existing plans and technical know-how, the drought revealed a stressed water system whose reliability has been diminished by 20 years of increasing demand. The São Paulo case study demonstrates the need for a more collaborative approach that brings transparent and open dialogue to water resources management.

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Richard N. Palmer

DEDICATION

Along my journey, I have been fortunate to meet relentless individuals who have dedicated their lives to issues bigger than themselves. To them, and to many others attempting what once seemed impossible, I dedicate this work.

“I love those who yearn for the impossible."
-Goethe

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Firstly, I thank the funding sources that supported my intellectual pursuit: the Center for a Livable Future through a Food Security and Climate Change Grant, the National Science Foundation with a Doctoral Dissertation Improvement Grant (#1457080), and the Schlumberger Foundation's Faculty for the Future Fellowship. The Faculty for the Future Fellowship was of particular significance to me because it supports a growing community of talented and bold women from developing countries who are changing the face of STEM at tech companies, government agencies, and academic institutions around the world. It has been my honor to be considered part of this community.

I am extremely grateful to a long list of teachers and mentors who nourished my curiosity over the years. Many of them believed in my abilities well before I did and challenged me to forge my path forward. I could not go without acknowledging Profs. Qson, Chen, Cizadly, McGahey, Robinson, and Sr. Agnes form my undergraduate years.

The writer David Foster Wallace's famous speech, *This Is Water*[1], begins with a story:

> There are these two young fish swimming along, and they happen to meet an older fish swimming the other way, who nods at them and says, "Morning, boys, how's the water?"
> And the two young fish swim on for a bit, and then eventually one of them looks over at the other and goes, "What the hell is water?

During my time in DoGEE, I grew deeply aware of my surroundings. I am eternally grateful to my dissertation committee for the breath and depth of their expertise. They taught me to examine what is water with a critical eye. This is water. *This is water!*

Prof. Benjamin Hobbs reoriented me in the right direction on more than one occasion. His depth of knowledge is what many academics aspire to. Prof. Margaret Keck's keen perspective on Brazilian water institutions was invaluable. She opened my eyes to the political complexity and reality of the Brazilian water scene. Prof. Richard Palmer dove into this project head on. At times, his selfless dedication of time and effort was all that kept me going. I thank him for holding my feet to the fire so that this work came to fruition. My advisor, Prof. Erica Schoenberger, allowed me the freedom to pursue the topics that most inspired me. Thank you, Erica, for keeping me honest in my pursuit of knowledge and for pushing me to ask the really hard questions.

[1] Story can be found in The New Yorker: http://www.newyorker.com/books/page-turner/this-is-water

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I thank Bill Werick, for helping me recognize my talent and teaching me to be unreasonably brave when the situation called for it. Rick and Bill, I want to thank you both for your patience and friendship, and for trusting me as you made your way down to Brazil in the thick of the drought.

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Lastly, I am grateful to the infinite mysteries of the universe that plotted in the stars that, in the pursuit of knowledge, a little girl from South America would one day walk among giants. Overcoming the odds was only possible thanks to God and her boundless generosity, for she gave me the courage to take the leap of faith over and over – and over – on this journey. As the daughter of an immigrant single-mother in the United States, faith and courage became a survival skill – a reminder to stop counting the obstacles and start counting my blessings.

Stefanie M. Falconi
December 19, 2016

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List of Acronyms

General

ABM – Agent-based Models

BN – Bayesian Network

ACT-ACF – Alabama-Coosa-Tallapoosa and Apalachicola-Chattahoochee-Flint

AusAID – Australian Agency for International Development

CIRAD – *Cooperation Internationale en Recherche Agronomique pour le Développement*

CORMAS – Common-pool Resources and Multi-Agent Systems

CPR – Common Pool Resources

GDP – Gross Domestic Product

GWP – Global Water Partnership

IWR – Institute of Water Resources [a USACE think tank]

IWRM – Integrated Water Resources Management

MCDA – Multi-Criteria Decision Analysis

MOU – Memorandum of Understanding

NGO – Non-government Organization

NRC – National Research Council

PM – Participatory Modeling

SDM – Systems Dynamic Model

SVM – Shared Vision Model

SVP – Shared Vision Planning

UN – United Nations

USACE – United States Army Corps of Enigineers

WRM – Water Resources Management

Brazil

ABRH – Brazilian Water Resources Association

ANA – National Water Agency

ARSESP – Regulating Agency for Public Service Concessions

AT – Alto Tietê

CBH – River Basin Committee (*Comitê de Bacia Hidrográfica*)

CETESB – São Paulo Environmental Sanitation Technology Company [state of São Paulo]

DAEE – São Paulo Water and Electrical Power Department [state of São Paulo]

GAEMA – Special Environmental Defense Working Group [within *Ministério Público*]

IBGE – Brazilian Institute for Geography and Statistics [Census Bureau].

MP – Public Ministry (*Ministério Público*) [Federal and State branches]

MRSP – Metropolitan Region of São Paulo

PCJ – Piracicaba, Capivari, and Jundiaí (rivers)

PSDB – Brazilian Social Democracy Party

PT – Workers' Party

SABESP – São Paulo State Basic Sanitation Company (*Companhia de Abastecimento Básico do Estado de São Paulo*)

SSRH – São Paulo State Secretariat of Water Resources and Sanitation

UNICAMP – University of Campinas [state of São Paulo]

GLOSSARY OF PORTUGUESE WORDS

Audiência pública: public hearing

Bacia hidrográfica – water basin

Câmara: chamber - *Câmara Técnica:* technical chamber or council

Código das Águas: Water Code.

Comitê: committee

Concursados: competition-based government positions

Decreto: decree

Grupo Técnico: technical group/team

Orgão: organism; body – *Orgão gestor:* management body

Outorga: granting of water use rights

Parecer Técnico: technical opinion

Portaria: Ministry or Secretariat Resolution

Racionamento: rationing of a more severe nature

Rodizio: to cut supply of water or rationing by turning off flow (depressurized)

Seca: drought

Técnico: technical expert; private consultants, university researchers and civil service officials with scientific or professional training

Volumem Morto: Dead storage

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CHAPTER 1. INTRODUCTION

1.1 Problem statement

Human activities such as agriculture, urbanization, industrialization, land use, and large-scale engineering schemes directly impact water resources and have greatly stressed the world's freshwater systems [*Rockström*, 2009; *Rockström et al.*, 2009; *Vörösmarty et al.*, 2010]. Even today, an estimated 1.8 billion people lack access to a safe and reliable drinking water source [*WHO*, 2016]. The water problem cannot be reduced to a question of scarcity; even in places of water abundance, lack of governing institutions, poor management, and uneven geographical and seasonal distribution of water resources can lead to water conflicts. These recognized threats prompted the search for an international framework to protect the health of the environment and of people [*UN-Water*, 2008], and motivated an international effort by "expert networks" to promote the principle of Integrated Water Resources Management (IWRM) [*Conca*, 2006]. Despite widespread adoption, IWRM has fallen short of its promise [Jeffrey and Gearey, 2006]. Science, technology, and engineering have long been proposed as part of the solution. However, water experts today also recognize the need to better understand the institutions and organizations that manage water.

In 1969, Dr. Abel Wolman assembled selected writings into his seminal book, Water, Health, and Society. He wrote about the need for new structures and a new generation of water professionals that could approach multidisciplinary problems in water with less compartmentalized expertise and in a more unified manner. His paper "Water—Economics and Policy," reflects on the success and failures of planned objectives by asking: "Has planning in the water resource field been panacea or delusion?" I would pose the same question today about IWRM. Of course, such a stark dichotomy does not really exist. Instead, the question is intended to force scientists and engineers – who play an important role in informing policy and public perception – to reflect on the current state of water management and planning and on its future. The JHU Department of Geography and Environmental Engineering (DoGEE) was founded based on the appreciation that a new generation of engineers were needed to address the environmental problems of our time. Hence, it seems appropriate that coming from DoGEE, my research strives to stand at the intersection of engineering and policy. A multidisciplinary education has the vantage point of bringing new perspectives to old problems. As society evolves and new demands and values are infused into the decision-making process, a new generation of professionals will be needed to navigate the changing field of water resources management. These professionals will be asked to transition smoothly between disciplines and work outside traditional boundaries, just as Dr. Abel Wolman predicted nearly 50 years ago.

At first glance, water management problems seem to fit nicely into a systems analysis problem where stakeholders' objectives are assessed and translated into a multi-objective analysis and optimal solutions (Pareto frontier) for allocating the available water resources. However, the field of water resource management has changed, and the need for greater participation has required the tools for analysis to change as well. The participatory process requires an analysis that goes beyond a prescriptive model for dealing with competing demands. Changes in the United States became most apparent at the turn of the twentieth century, but have become more persistent and widely spread in the last 60 years [*Boland et* *al.*, 2009]. One such change was the expansion of the water resources management (WRM) dialogue to include a multiplicity of actors and disciplines who entered the playing field as IWRM came into focus around 1994. Thus, water resource planning and management went from being "primarily the province of engineers, with occasional inputs from economists" [2] [*Boland and Baumann*, 2009, p.1] to being an interdisciplinary, international dialogue. The inclusion of such diverse actors resulted in a surge of new perspectives and opinions on how water should be governed and managed. Equally importantly, the change also sparked criticism, resistance, frustration, and incompatible perspectives concerning the direction in which the WRM dialogue should proceed.

Interestingly, a similar complication emerged within IWRM when it proposed to shift decision-making from a centralized, government-led, albeit fragmented, [3] process to a decentralized, integrative, and participatory process that included diverse stakeholders. These stakeholders were not homogeneous nor were their interests and objectives similar or compatible. Complicating matters, experts have pointed out that water is among the first means by which climate change is already affecting humans [*Karl et al.*, 2009; *Sadoff and Muller*, 2009], and whether it is felt as drought or floods, it will mean adaptation to a new environment. How then are computer models useful in this multi-layer, complex context? Governments, institutions, and ultimately people need to understand and act on technical information in order to adapt. It is not self-evident, however, how scientific and technical

[2] Boland and Baumann's chapter *The Evolution of Water Resource Planning and Decision Making* is also paraphrasing from the introductory to the Design of Water-resource Systems by Maass et al. (1962).

[3] These are not contradictory statements since decisions can be made within a federal or State planned framework but in different agencies and for different sectors of water.

knowledge will inform those decisions. One can see today that in questions of resource management, what was once a relatively straightforward matter handled by engineers and government agencies has become a complicated and arduous process with new actors and different interest pushing diverse agendas at the proverbial negotiating table.

1.2 Research question and study objectives

At the core of this study are questions of how computer models support decision-making, how technical knowledge can be translated into policy, and whether model building can strengthen adaptive governance. With changing water governance regimes came the need for greater participation of pluralistic actors, and models needed to be accessible to non-technical participants. To do so, computer models needed to incorporate new aspects of decision-making: a) to include more diverse set of values and objectives, b) to account for institutional and sociopolitical differences that can translate to conflicting problem definitions, c) to define the purpose and expectations of a decision process, and d) to help improve decision mechanisms.

For a long time, traditional WRM tended to overlook or minimize the role of governance under the prescription that optimizing for economic efficiency and rational behavior would lead to better decisions. More recently, under IWRM, new concepts of participation, decentralization, and integration have emerged, paving the way for new power relations and decision-making mechanisms [*Conca*, 2006; *Molle*, 2009]. In this new paradigm, river basin councils and the governance challenges they face in exercising their role as decision-making units have become an interesting topic of study.

The study objectives are:

Objective 1. Identify the characteristics that make computer models effective at engaging stakeholders in a participatory policy process.

Research questions addressed in Chapter 2:

1. How has the field of water resource management worked to improve public participation?
2. What role do computer models play in bridging technical knowledge to the public policy process?
3. What mechanisms make computer models effective as participatory decision tools?
4. How can participatory computer models be designed and evaluated on their technical and non-technical aspects of informing policy?

Objective 2. Examine the case study of joint water management in the Cantareira system in São Paulo, Brazil to identify the institutional challenges to achieving improved participation and water governance.

Research questions addressed in Chapter 3:

1. What role did technical information play in the state's response to the drought?
2. What aspects of politics and power exacerbated the natural drought event?
3. What major impediments to collaboration exacerbated São Paulo's drought?
4. What are the institutional challenges in building water governance?

Objective 3. How can collaboratively developed computer models support a formal and disciplined approach to drought planning that incorporates stakeholders' concerns? Given

São Paulo's unprecedented drought, how could drought planning have been more transparent if a collaborative modeling framework had been possible?

Research questions addressed in Chapter 4:

1. How could Cantareira system operations be managed to mitigate the reliability of the system and the costs to users and the utility company?

2. How can we assess system performance measures of the Cantareira under different drought indicators, triggers, and actions to create alternative plans?

3. How can drought planning be improved in a collaborative manner to minimize the drought's negative impacts?

To answer these questions, this study made use of a mixed-method approach including qualitative and quantitative methods. Qualitative tools were used in interviews, meeting attendance, and content analysis of technical documents, which were the basis for developing the case study in São Paulo, Brazil. Quantitative methods were used to help develop a participatory model of the Cantareira water supply system that was presented at two public workshops in May 2014 and March 2015. The qualitative methods informed decision to present at the two workshops a collaborative modeling framework for the region that incorporates the challenges and opportunities identified by local stakeholders through interviews. Appendix B provides a methodological note on the interviews and meetings.

The thesis is organized as follows: The remainder of this chapter provides background information on the major concepts in the changing field of water resource management. It is meant as a foundation to understand the complexity of the topic. Chapter 2 explores the five dimensions of participation and the complexity of creating models that are more timely, flexible, transparent, and relevant to the needs of the public. Chapters 3 and 4 provide different perspectives on São Paulo's water crisis: Chapter 3 documents the historic drought that affected São Paulo and analyzes the institutional challenges to participation despite a history of active institutions in the study region, while Chapter 4 is a technical analysis of system performance and post-workshop analysis on participatory drought planning. Finally, Chapter 5 concludes with the implications and impacts of the present study on water resource management and outlines how this interdisciplinary perspective on models and the policy process can be applied in the context of IWRM. This research is relevant to engineers who strive to build computer models that can improve decisions through increased transparency, access to information, and representative stakeholder engagement.

1.3 Theoretical frameworks

At the nexus of models, participatory water resources management, and governance, there are interdisciplinary questions that challenge not only how problems are defined but also the guiding assumptions. Consequently, this research draws on several disciplines in order to provide a broad understanding of the theory and practice of participatory modeling as it applies to improving the policy process.

1.3.1 Definition and origin of Integrated Water Resources Management (IWRM)

On the international stage, where discussions on how to manage global water resources are underway, IWRM is what *Conca* [2008] refers to as "the discursive framework of international water policy." The most frequently cited definition of IWRM comes from the

Global Water Partnership (GWP):[4] "IWRM is defined as a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." The UN describes IWRM as the "approach that has now been accepted internationally as the way forward for efficient, equitable and sustainable development and management of the world's limited water resources and for coping with conflicting demands" [*UN-Water*, 2008, p.1].

It should be noted, however, that the concept of integrative management was thriving as far back as the Tennessee Valley Authority in 1933 [*Viessman et al.*, 2009]. Experts in the field of WRM had recognized the need for comprehensive plans with less fragmented policies many years before the term "IWRM" was coined, and they fostered frameworks such as "integrative river basin management" and "comprehensive river basin planning." The difference is that these frameworks emphasized the technical and managerial characteristics of WRM. With time, WRM has been overshadowed by the growing popularity of IWRM. *Lautze et al.* [2011] observed that once IWRM emerged in the international dialogue in the mid-1990, the terms "water management" and "IWRM" began to be used interchangeably, and water management grew "increasingly moot as use of the term is frequently supplanted by IWRM" [2011, p.5].

[4] The GWP is a partnership between the World Bank, the United Nations Development Program, and the Swedish International Development Cooperation Agency. It promotes the implementation of IWRM.

Those experts familiar with WRM did not have to change much in practice in order to adopt the IWRM dialogue. The discourse of IWRM is vague and leaves much room for interpretation [*Conca*, 2006; *Abers and Keck*, 2013]. It is unclear if this discourse has translated into actual operational changes [*Priscoli*, 2004]. What is clear is that: 1) IWRM emerged at the international level as a discourse on how to manage the world's water resources; 2) the framework of IWRM was embraced by multiple actors and organizations, even without an agreed-upon definition; 3) IWRM language resembles that of WRM, although its legitimization was not confined to the WRM community; 4) the concept of IWRM eventually rose to dominate the field of WRM.[5] Unpacking IWRM and its operational challenges requires a broader disciplinary perspective.

Environmental issues entered the international water agenda in the 1970s and have grown in prominence ever since. A few notable international events include the United Nations (UN) Water Conference in Mar del Plata, Argentina in 1977, the UN General Assembly in 1980 that marked the International Drinking Water Supply and Sanitation Decade, and the UN Conference on Environment and Development (termed the "Earth Summit") in Rio de Janeiro in 1992. IWRM surfaced from such discussions [*Conca*, 2006; *Orlove and Caton*, 2010]. The main guiding tenets of IWRM were described in the Dublin Principles drafted months prior to the Earth Summit in Rio de Janeiro, 1992 [*UN*, 1992]:

a. Fresh water is a finite and vulnerable resource, essential to sustain life, development, and the environment.
b. Water development and management should be based on a participatory approach, involving users, planners, and policy makers at all levels.

[5] For a full history of the development of IWRM, significant accounts already exist by Conca (2006), Varady et al. (2009), Varady & Iles-shih (2005), Rahaman & Varis (2005), Biswas (2004), and Mukhtarov (2009).

c. Women play a central part in the provision, management, and safeguarding of water.
d. Water has an economic value in all its competing uses and should be recognized as an economic good.

In summary, IWRM established water as an economic good with multiple, and often competing, uses that needs to be managed in a holistic and participatory manner in order to maximize the economic and social welfare of its users.

1.3.2 Critiques and shortcomings

Despite the international acceptance and legitimization of IWRM among water experts, and despite the fact that a number of countries have written IWRM principles into their water law, the IWRM framework has also been met with controversy. IWRM is not a concept with a static definition; it is a "living discourse" [*Mukhtarov*, 2009, p.4] that assumes different expressions and forms, sometimes for the benefit of those pushing a particular agenda. A number of social and political scientists point out the plurality of agents acting within the human-environmental systems in question. They argue that the people and objectives being modeled are neither a homogenous nor collective group of stakeholders. Communities have also protested, often contending the persistently exclusive nature of the decision-making process. Even the meaning of words such as "integrative" and "participatory," central to the IWRM principles, varies widely among experts and according to context. A doctoral dissertation on the hegemony of IWRM explains IWRM as follows:

> Despite its sweeping popularity, there is little agreement on what IWRM actually constitutes. There is an on-going debate on the basic meaning, scope and nature of IWRM. Over thirty IWRM definitions can be found in the literature. This diversity is not surprising *per se*; what is striking is that despite being vaguely defined and lacking proof of effectiveness on the ground, IWRM became very popular on the international water policy arena. [*Mukhtarov*, 2009, p4]

These critiques point to the inconsistencies and incongruent narratives within IWRM. For example, participatory processes can result in unsustainable outcome if those involved choose their own benefit over environmentally sustainable options. Yet, IWRM remains the most disseminated framework on sustainable water management. IWRM has been promoted as an ideal framework in which all stakeholders (and to an extent all actors in the water dialogue) could reach common ground. It is of little surprise, then, that IWRM has not lived up to its promise; it seems its list of promises grew at every step. This in part explains why the IWRM paradigm has mostly remained a normative theory on what ought to be done without concrete policies or plans for how to carry it out [*Jeffrey and Gearey*, 2006; *Medema et al.*, 2008].

1.4 The eras of water resources management

The focus of this section is to understand the emerging trends in management and theories that have informed water resource practice. It is helpful to consider the recent history of water resources management as a series of eras.

1.4.1 Era of large engineered infrastructure

The large infrastructure era was marked by "heroic engineering feats" through the manipulation of rivers and other water sources by damming, diverting, and dredging [*Conca*, 2006]. These projects were organized with a very centralized, top-down approach. There are roughly 800,000 dams spread across the globe, of which slightly over 40,000 are considered large dams.[6] These large dams include roughly 300 major dams[7] such as Aswan, Hoover, and Itaipu [*Oud and Muir*, 1997; *Conca*, 2006]. River manipulation has been "vastly larger and more aggressive" in the twentieth century [*Sabatier et al.*, 2005, p.45] compared to earlier time periods. Of the existing 40,000 large dams, most were built in the second half of twentieth century.

For much of this era, management was a process dictated by the state, and more specifically by the technocrats who were in charge of "command-and-control" engineering plans. Economic development played an important role in the construction of dams and other major infrastructure projects, and the prevailing objective was generally to increase water supplies. In fact, for many regions water has often been the "key to growth," and once an area developed its water resources, "it acted to protect its development with political muscle commensurate with its increased wealth" [*Ingram*, 1969, p.10]. The era of dam building peaked in the 1970s, and the rate of construction has been decreasing since [*Oud and Muir*, 1997; *Conca*, 2006].

1.4.2 Era of "soft" path and multi-objectives

In the past 50 years, water management has undergone a "quiet revolution" [*Sabatier et al.*, 2005, p.33]. Today most water experts recognize the importance of institutional

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[6] Large dams are defined by International Commission on Large Dams as waterfalls with heights larger than 15 meters high.

[7] Major dams are defined by International Commission on Large Dams as dams that meet one or more of the following criteria greater than 150meters height, greater than 15 million m^3 volume, greater than 25 billion m^3 reservoir volume, or greater than 1000MW electric generating capacity.

arrangements and effective governance for making technical solutions possible. This change has meant an increased acknowledgement that human systems and freshwater ecosystems are inevitably entwined.

As with any change of this magnitude, the paradigm shift did not occur overnight. It was a gradual progression. In the US, however, most water experts can point to a specific year that marked the start of the new era of water management. In 1969, the Senate Select Committee on Water Resources made broad recommendations and approved the initiation of "radically new policy directions" by the Executive Branch [*Viessman et al.*, 2009, p.27]. The decade predating these changes was characterized by a wave of environmental concerns and public demands that environmental quality be included in federal- and state-level evaluation of projects. This period also witnessed changes in project evaluation methods, with more refined tools for informing policy and decision-making as federal government began to favor multi-objective management and comprehensive planning over single-purpose or individual projects.

The changes marked by the Senate recommendations came at a time when environmental topics were being debated and a convergence of other interests pushed for more action from the government. This climate produced several environmental milestones in the US, including a number of laws and regulations that mandated public involvement: the National Environmental Protection Act (NEPA) of 1969, the Clean Water Act of 1972, and the Principles and Standards of 1973. NEPA, for example, requires Environmental Assessments or Environmental Impact Statements for federal water decisions that significantly affect the environment, and further requires the opportunity for public review and comment on these documents. This was the era of full disclosure, but stakeholder and regulatory agency involvement still came at the end of the process, when plans could not be changed significantly. At least in the United States, the paradigm shift after 1969 was a significant push forward for stakeholder inclusion, even if only on paper, in management and decision practices.

The steady change in US water policy that marked those 50 years also included the emergence of "soft" path solutions to water management, such as mathematical models and systems analysis. Water expert Peter Gleick [2003] talks about a "changing water paradigm" that progresses from "hard" path solutions, which tend to focus solely on infrastructure (such as dam construction), to "soft" path solutions that also emphasize people, technologies, and efficient use of water. Peter Loucks has further characterized this paradigm shift as a change from a supply-side increase to efficiencies in demand-side management [*Loucks*, 2000]. Systems analysis is the formal mathematical modeling that has been employed to optimize water supplies and improve water planning and management decisions [*Loucks*, 2000]. Systems analysis as a field has grown to include analytical tools beyond optimization and operations research,[8] and its methods have permeated disciplines from industrial engineering and engineering management to economics and finance, to name but a few. What these fields have in common, and what systems analysis provides, is clear and concise deliberation

[8] Operations Research and Systems Engineering disciplines are traced to the development of linear programming by two central figures: Koopmans in the U.K. and Kantorovich in former U.S.S.R. In 1947, George Dantzig showed how to solve Koopmans' problem with a practical simplex algorithm as applied to a U.S. Air Force research program. Prof. Abraham Charnes is credited with pushing the first applications of OR and LP in civil and environmental engineering (ReVelle et al. 2004).

between multiple alternatives. However, as Charles ReVelle points out: “Of all the environmental areas to adopt systems methodology, probably the most active applications have taken place in water resources and water quality management” [*ReVelle et al.*, 2004, p.13].

The convergence of system analysis and hydrology as a method to study water resources was pioneered by the Harvard Water Program (HWP), which in 1955 began combining “advances in probability theory, statistics, operations research and welfare economics” to inform management practices [*Boland et al.*, 2009, p.93]. The HWP’s research purpose was to improve methods for designing water resources systems. The HWP was also the first to study complex river basin systems by incorporating aspects of social science, making one of its principal goals “to improve the methodology of systems design by joining engineering and economics more effectively than has been done in the past” [*Maass and et al.*, 1962]. The methodology involved identifying design objectives, translating objectives into design criteria, optimizing specific water systems, and evaluating the consequences of development plans [*Reuss*, 2003; *Maass et al.*, 1962]. There is no question that the HWP and subsequent academic and research institutions contributed significantly to the field of water resource management and planning. In U.S. Army Corps of Engineers Senior Historian Michael Reuss’ words:

> Clearly, the multi-objective analysis and computer simulations pioneered at Harvard anticipated the interdisciplinary approach that today dominates watershed planning…The papers and discussion in the Harvard seminar directly led to the publication of Design of Water-Resource Systems: New Techniques for Relating Economic Objectives, Engineering Analysis, and Governmental Planning (Maass et al., 1962). Professors and students shared in writing the chapters. The topics included mathematical models, computer simulations, economic concepts and evaluation, the political process, and operating procedures for water systems. The book remains a

> landmark in the attempt to integrate social science and engineering variables to develop the optimal water resources system. [*Reuss*, 2003, p.358]

Other important intellectual forces that added to the economic analysis of WRM during this era were Resources for the Future and the RAND Corporation. These and other academic contributions and controversies from the economic perspective are recounted by Boland and Baumman (2009) in "Evolution of Economic Analysis through a Historical Lens."

1.4.3 Emergence of water governance under IWRM

Another important event on the international stage that facilitated the spread and uptake of IWRM was the emergence of the global environmental governance concept [*Johal and Ulph*, 2002; WRI, 2003]. This thesis focuses on water governance, but the concept of water governance does not exist in a vacuum. Rather, it fits into a larger international movement for environmental governance. Consequently, environmental and water issues started to be discussed internationally as idealized global strategies for decades to come.

In practice, water governance remains a difficult concept to define and implement because problems are poorly defined and multi-layer in nature, and decision-making roles are fluid and involve multiple stakeholders. Yet we see that prior to the emergence of water governance, most natural resource management analysts assumed the existence of a single decision maker [*Mendoza and Martins*, 2006]. Traditional methods for decision-making were criticized for their lack of flexibility to deal with the challenges that new and diverse participants brought to the decision-making process. The assumptions in traditional (computer) modeling limited its application to situations in which problems were well defined, involving organizational structures in which participants had a defined role and where perspectives, and priorities were not widely divergent [*Churchman*, 1967; *Ackoff*, 1979; *Checkland*, 1983; *Rosenhead*, 2006; *Mingers*, 2009]. As the principles of IWRM gain traction at all levels of the water dialogue, a better understanding of water governance is needed. The frequent attempt to depoliticize water problems and gloss over water governance has real implications for how water is allocated.

1.5 Contribution

This research explores the relationship between computer models, stakeholder participation, and adaptive governance within water resource institutions. "IWRM, the centerpiece of world debate on water policy, cannot be achieved without participatory processes" [*Priscoli*, 2004, p.226]. Yet IWRM defines participation in vague terms, leaving it open to interpretation. This research aims to strengthen adaptive governance capacities within institutions adopting the IWRM paradigm by finding effective ways to engage the public in a collaborative modeling process.

IWRM can seem like an elusive concept, but Brazil's water reform and current drought experience provides concrete evidence of the different ways that participation can take place in the deliberation process. This evidence highlights the importance of stakeholder inclusion in model building and understanding of technical knowledge. How interactions are orchestrated makes a significant difference. This work, and the analysis of case studies therein, is particularly relevant as countries who have turned to the IWRM framework scramble to figure out how to include a diverse set of actors in the deliberation process.

At the core of this study are questions of how and when computer models support decision making; how scientific knowledge gets incorporated into policy (if it does at all); and whether meaningful participation can strengthen the modeling, decision, and institutional building process. Conventional wisdom holds that models are relevant to decision making because better information leads to better decisions. However, the relationship of models to a technically informed public is not straightforward, and the rules of engagement (who, when, why, how) make a significant difference in whether information gets used to democratize or insulate decisions in the policy processes. Chapter 2 on participatory models and their interdisciplinary nature shows mechanisms to improve the role of models in stakeholder engagement. The case study presented in Chapters 3 and 4 elucidates the institutional and socio-political realities that are important drivers in water management decisions, but are often glossed over within the IWRM technical discourse.

CHAPTER 2. An Interdisciplinary Framework for Participatory Modeling Design and Evaluation—What Makes Models Effective Participatory Decision Tools?[9]

2.1 Introduction

A fundamental challenge in natural resource management is the integration of both technical information and effective public participation, a key component in democratic decision-making [*NRC*, 2008]. While it is generally accepted that technical knowledge can lead to more informed and effective decisions, empirical studies also show that the "difference between democratization and insulation rests on the rules of engagement of stakeholders and the practices regarding the availability and accessibility of knowledge" [*Lemos*, 2008, p.253]. The empirical evidence highlights the need to improve practices for engaging stakeholders and using scientific and technical information in democratic processes that support open debates about alternatives. This chapter discusses the role of computer models in addressing these challenges.

In the US, public participation in Water Resources Management (WRM) dates to the 1920s [*Creighton and Langsdale*, 2009]. In the second half of the twentieth century, decentralized and participatory management increased when project funding responsibilities shifted to state and local governments [*Priscoli*, 1989, 2004]. At the same time, the US's landmark environmental laws greatly expanded the rights of citizens to participate in public decision-

[9] An abridged version of this chapter has been accepted to the *Journal of Water Resource Research*, Falconi, S.M., and Palmer, R.N. (2017). Falconi wrote initial and revised drafts of the paper and of this present chapter.

making [*Davis et al.*, 1975; *Ertel and Koch*, 1976; *Ertel*, 1979]. These important laws and regulations included the National Environmental Protection Act (1969), the Federal Clean Water Act (1972), the Endangered Species Act (1973), and a policy document, Principles and Standards for Planning (1973). Increased public participation resulted in conflicts and public interest lawsuits that eventually prompted federal agencies to invest in alternative dispute resolution techniques to improve stakeholder involvement.

Efforts to secure stakeholder involvement are not limited to the United States. Emphasis on stakeholder participation is a prominent feature of the European Water Framework Directive [*Commission of the European Communities*, 2000], as well as in the international discourse on water policy known as Integrated Water Resource Management (IWRM) [*UN-Water*, 2008]. Moreover, the guiding tenets of the Dublin Principles on Water and Sustainable Development, which served as the basis for Agenda 21 at the Earth Summit in Rio de Janeiro 1992, placed participation at the center of discussions on environmental management [UN 1992; *Jønch-Clausen*, 2004]. IWRM emerged as the dominant paradigm for managing water worldwide through the democratization of water management. It emphasizes three pillars: efficiency, sustainability, and equity [*UN-Water*, 2008; *Mukhtarov*, 2009]. The Global Water Partnership echoed the USA's Principles and Standards for Planning (1973) when it defined IWRM as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." As interest in IWRM has grown, the question of how to best engage stakeholders to improve adaptive management and institutional capacity remains [*Jeffrey and Gearey*, 2006; *Medema et al.*, 2008].

The field of participatory modeling (PM) emerged from the need to integrate stakeholder engagement in an open and transparent discussion facilitated by structured processes that address the needs and objectives of collaborative decision-making [*Dreyer and Renn*, 2011]. Different disciplines have coined varying names for PM, and their various origins suggest important differences in their approach. For example, integrated assessment professionals use the term "participatory modeling," while the system dynamics community refers to "group model building" or "collaborative modeling" processes. The operations research disciplines use the term "decision support systems" for interactive models that may be used for stakeholder engagement [*Loucks et al.*, 1985; *Vennix et al.*, 1999; *Van Asselt and Rotmans*, 2002; *Stave*, 2003; *Cockerill et al.*, 2006; *Langsdale et al*., 2009] and "shared vision planning" when planning is combined with stakeholder involvement [*Palmer et al.*, 2013]. Regardless of what it is called, the defining feature of PM is that it engages participants in the development of a computer model that facilitates some aspect of collaborative dialogue and negotiations in environmental and water resource management [*Bourget*, 2011].

This chapter identifies mechanisms to improve the effectiveness of such models in participatory efforts. The unique contribution of this chapter is a two-stage analysis framework derived from five empirical case studies. This framework first characterizes the five dimensions of participation (stage 1) and then evaluates participatory models based on the concept of “boundary objects” (stage 2). Boundary objects are defined as translation devices at the interface of different organizations or groups that can act as bridges to facilitate mutual understanding and cooperation [*Huvila et al.*, 2014]. In the case of participatory modeling, the boundary object is the computer model that is constructed during the participatory process, and which ideally wins the trust of stakeholders from many different backgrounds. The goal of our analysis framework is not to evaluate the outcome(s) of participatory modeling, nor is it to identify the characteristics of the “best” models and modeling approaches in a participatory context. Instead, our objective is to propose and categorize common *mechanisms* that promote model effectiveness across a wide range of participatory decision-making contexts, forms of participation, and types of computer models. Mechanisms are combinations of activities, processes, and characteristics that together form the means by which intermediate outcomes come about. These concepts will be developed in greater depth over the course of this chapter. We argue that a structured vocabulary and a multi-dimensional, interdisciplinary evaluation framework can improve both the design and the documentation of participatory models in water resources conflicts. This chapter is organized as follows: Section 2.2 outlines challenges in evaluating participatory models and reviews evaluation methods; Section 2.3 provides a motivation for the proposed framework; Section 2.4 outlines stage one of our framework and characterizes the five dimensions of participation as they relate to models; Section 2.5 presents the concept of models as boundary objects, describes characteristics of effective PM, and lays out corresponding criteria for stage two of the evaluation framework; Section 2.6 uses the two-stage process to evaluate five case studies; Section 2.7 provides lessons from the case studies and evaluation framework; Section 2.8 summarizes and concludes the analysis on participation in WRM.

2.2 Evaluating participatory models

2.2.1 Challenges

The combination of public participation and models presents several challenges for the evaluation of PM efforts. WRM problems have often been referred to as "wicked," given their tendency to present unclear problem statements, diverse stakeholders, contentious and/or multiple objectives, and negotiated solutions [*Rittel and Webber*, 1973; *Liebman*, 1976; *Pidd*, 1999; *Xiang*, 2013]. Indeed, the complexity of WRM requires the interdisciplinary critical thinking and problem-solving skills that have been identified as necessary to address other environmental problems [*Wolman*, 1977].

Thirty years ago, in a landmark paper, Rogers and Fiering [1986] presented an analysis of the infrequent application of systems models in government and real-world projects, concluding that "models are not usually concerned with what decision-makers care about" [*Rogers and Fiering*, 1986, p.149]. They argued for more practical models with greater flexibility in both assumptions and applications. Their assessment remains relevant today. Several studies have tried to evaluate the benefits of participation and the benefits of using models in participatory efforts. However, designing an evaluation process has proved difficult, as real water conflicts have uncontrollable variables and do not allow a "with" and "without" model comparison, so determining the effectiveness of participatory models requires careful interpretation of model use in past decision-making efforts. Furthermore, as mentioned previously, a plurality of participatory modeling approaches are used across different disciplines. This diversity of existing approaches to participatory modeling complicates both evaluation of individual models and comparative evaluations that may help advance the field of PM. Previous evaluations of participatory models have emphasized the assessment of processes, intermediate outcomes, and resources outcomes. The distinction between these three stages is presented below.

Creighton & Langsdale [2009] review twenty-one water supply and drought case studies for efficacy and identify PM characteristics that are critical to the participation process. They recognize the limitations of documented case studies and recommend future research on how the level and method of stakeholder involvement affect: 1) the credibility and adequacy of the computer model, 2) the political acceptance of the recommendations, and 3) the stakeholders' ability to participate in the model building exercise.

Michaud [2009] provides methods for analysts to evaluate outcomes of PM efforts based on participant interviews and surveys. Michaud's evaluation method relies on the similarity of the comparative case studies, but his conclusions do not provide a structure for characterizing the purpose or nature of the participatory effort.

Carr et al. [2012] provide an extensive evaluation of participation (without models) in natural resource management assessments, in which they classify processes, intermediate outcomes, and resource management outcomes. We discuss these classifications in more detail in the following subsections, since their distinctions are critical in building our evaluation framework.

2.2.2 Process

Process in this case refers to the series of actions or events (e.g., ground rules, representation, deadlines, access to information) that lead to a given outcome, but the process is not the outcome itself. Hence, participatory process evaluations focus on how participation was conducted in terms of factors like participant accountability, agenda, facilitation, and clear ground rules, under the assumption that processes that do well on those factors are more likely to yield good outcomes. Past studies have proposed several instruments for evaluating processes, most notably surveys, interviews, questionnaires, and performance measures.

2.2.3 Resource management outcomes evaluations

Outcomes evaluations gauge how well the ultimate objective was achieved. They are retrospective in nature. *Carr et al.* [2012] offer five examples of ultimate outcomes, as well as evaluation criteria for each. These outcomes include ecological and economic improvement, human health outcomes, implementation of plans, and reduced conflict.

Evaluations based on resource management outcomes can be more challenging and more limited than evaluations based on process or on intermediate outcomes for several reasons. First, there is usually no control against which to measure the results (e.g., drought, environmental damage). Second, criteria for assessment are often narrowly defined, and may therefore miss other important impacts. Finally, a number of uncontrollable factors external to the participatory process could influence ultimate outcomes (e.g., changes in regulatory or political climate). Ultimate outcomes are not limited to those from the five-point typology of *Carr et al*. [2012]: they also include decisions/actions taken with regards to resource management. In the long-term, ultimate outcomes can also include such features as consistent recommendations or adaptive management capacities that resulted from the original participatory exercise.

2.2.4 Intermediate outcomes

Intermediate outcomes are the incremental benefits of participation, often unplanned, that can build trust, communication, networks, agreements, institutional capacity, and other intangible outcomes. For the purposes of our study, intermediate outcomes are arguably the most interesting, since they are directly indicative of the participatory process and are more accessible and readily documented than resource management outcomes. *Carr et al.* [2012] provide intermediate outcome examples such as: agreements, network development, shared knowledge and end to stalemate. They argue that while these are often overlooked because their benefits may be hard to measure, intermediate outcomes should still play a more significant evaluative role because their benefits are short- or medium-term and become visible before ultimate outcomes.

Taken together, *Creighton and Langsdale* [2009], *Michaud* [2009], and *Carr et al.*, [2012] provide evidence of the value of intermediate outcomes and the need to look beyond ultimate outcomes when evaluating participatory modeling efforts. These studies demonstrate the need to evaluate PM despite the diversity in PM approaches, the wide range of goals of PM, and other inherent challenges mentioned above. In response, we propose PM evaluation criteria based on process mechanisms and on their relation to intermediate outcomes. These criteria are outlined in Section 2.5.

2.3 Motivation and contributions

Public participation, an inherently social concept, has been interpreted inconsistently within IWRM [*Conca*, 2006; *Abers and Keck*, 2013]. As democratization and public participation brought new actors to the negotiating table, new modeling tools and methods were required to incorporate diverse knowledge and perspectives into the mathematical language and formal logic of models [*Palmer et al.*, 2013]. The disciplinary differences and the variety of participatory contexts in which models are applied posed specific challenges in creating systematic evaluations. As a result, evaluation of these models cannot be based on a single disciplinary metric.

The novel contribution of the proposed two-stage evaluation framework is three-fold. First, the framework is uniquely designed to incorporate the technical and social nature of PM, based on a five-dimensional characterization of participation (stage 1) and on the concept of models as effective boundary objects (stage 2). Second, the criteria we have developed extend beyond the existing process- and outcome-based evaluations to focus instead on mechanisms. Consequently, mechanisms are the means by which models facilitate dialogue and resolution or the transformation between process instruments and desirable outcome. Third, the framework allows flexibility to evaluate a wide range of cases, even in studies where the stated objectives for participation are quite different in scope or discipline. As discussed in section 2.4.3, the goals of public participation can be diverse. They may, for example, seek to establish priorities in funding, to solicit risk acceptance, or to actually empower participants in a negotiation process. Our framework for evaluation of a participatory model is based on both the model itself and the model's impact in the participatory context, without attempting to separate the "success" of the model from the "success" of public participation.

2.4 Stage one: Dimensions of participation

The National Resource Council [*NRC*, 2008] identified five dimensions of public participation in environmental decision-making:

1. Who is involved?
2. At what stage in the planning process are the participants involved?
3. What is the degree and effort of involvement of the participants and the organizer?
4. What extent of power and/or influence do the participants have in the decision process?
5. What are the goals and purposes guiding the participation process?

The following sections explore how to characterize each of these dimensions and their relationship to modeling (Figure 1.1).

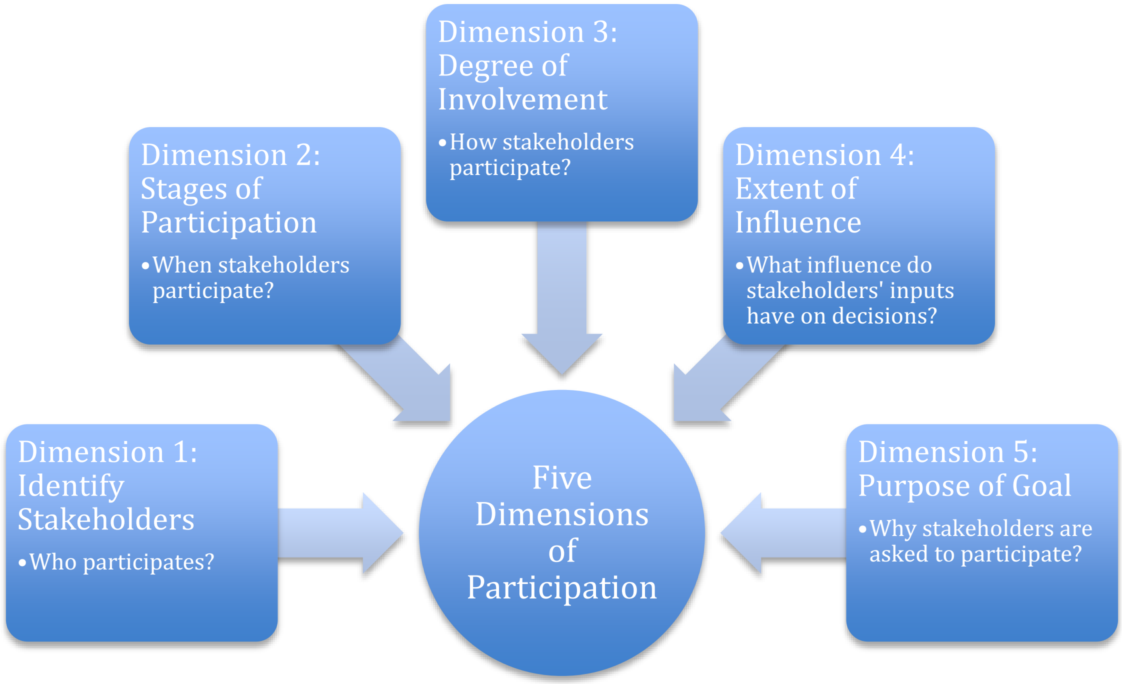

Figure 2.1 Summary of Five Dimensions of Participation

2.4.1 Dimensions 1 and 2: Identifying stakeholders and stages of participation

Defining the appropriate participants in public decision process is often challenging and rarely straightforward. The goals of participation (see Section 2.4.3) typically suggest which participants are essential if these goals are to be met (e.g., technical experts, civil society, interest groups). For example, gaining political acceptance requires engaging diverse groups that may need to reach consensus. Public participation is an iterative process that can take significant commitment and effort from everyone involved. Organizing public meetings at the initial stages of the planning process is effective in identifying appropriate stakeholders. However, analysts must be aware that stakeholder inclusion or exclusion may foster sociopolitical polarization that can affect the long-term impacts and success of the planning process.

There is no definitive prescription for identifying and engaging stakeholders because those selections depend on the problem at hand. However, suggested methods exist to aid in balancing between inclusiveness and maintaining effective group size. *Grimble and Wellard* [1997] and *Colfer et al.* [1999] suggest methods for formally identifying, selecting, and engaging appropriate stakeholders. *Herath* [2004] provides a systematic stakeholder selection process through focus groups and demographic analysis combined with a snowball effect where early stakeholders suggest the subsequent stakeholders.

The timing of stakeholder and decision-maker engagement must also be defined. Simple classifications (such as *a priori*, during, and *a posterior*i participation) have been suggested [*Mendoza and Martins*, 2006], along with more detailed classifications based on the five stages of participatory model development [*Hare*, 2011]:

1) *Data collection*—collect or provide existing data on the system
2) *Model definition*—individual engagement (e.g., structured and unstructured interviews) or collective engagement (e.g., cognitive mapping exercises) to identify important components of the system to be modeled.
3) *Model building and construction*—use of causal diagrams or influence diagrams during group model exercises that are then used in the model building process.
4) *Model verification and validation*—engage in the verification and/or validation of the model's content or results. This can be done through questionnaires or focus groups.
5) *Model application*—make use of the model in a structured manner such as direct use, role-playing games, use-by-demand, etc.

In practice, PM stages such as the five described by *Hare* [2011] are often combined or blurred. In the literature, models are used to inform stakeholders about the system and the interactions between system components [*Gilbert and Bankes*, 2002; *Barreteau et al.*, 2010]. Models are also used as scenario-analysis tools for policymakers [*Rajan and Shibasaki*, 2000; *Verburg et al.*, 2004; *Ligtenberg et al.*, 2009; *Webler et al.*, 2011]. Occasionally participants are involved in all five stages, and researchers co-generate model inputs, structure, and results [*Bousquet et al.*, 1998; *Hare et al.*, 2003; *Lynam et al.*, 2007]. The problem is that descriptions of model development in the literature frequently omit specifics about when stakeholders were engaged. Instead, researchers commonly use the term "participatory modeling" in a generic manner without clarifying when or how participation took place [for example see *Vennix et al.*, 1999].

2.4.2 Dimensions 3 and 4: Degree of involvement and extent of influence

Degree of involvement and extent of influence are constructed scales of how participants' engagement translates into influence on decisions. For example, Arnstein's ladder of participation [1969] ranks various forms of public participation on an eight-step ladder from least to most influential. Other analogous continuums (e.g., formative participation and objective-driven participation) also measure engagement on constructed scales [*Cornwall*, 2008]. Generally speaking, Arnstein's ladder and other scales rank the degree of involvement and the extent of influence of stakeholder participation. However, these two factors are not easily separable, because the degree and effort of involvement by participants and organizers sometimes determines how much stakeholders influence decisions.

This research applies the International Association for Public Participation's characterization of influence and involvement to discuss these dimensions. These characteristics are deemed appropriate for this context, because the different levels of participation may be applied across different resource management problems since the characteristics relate to other constructed scales without ranking them (Table 2.1).

Table 2.1 Levels of involvement and extent of influence in public participation (Adaptation from [*International Association for Public Participation*, 2005])

	INFORM	**CONSULT**	**INVOLVE**	**COLLABORATE**	**EMPOWER**
Level of Influence Public Participation	To provide the public with balanced and objective information to assist in understanding the problem, alternatives, opportunities, and/or solutions	To obtain public feedback on analysis, alternatives and/or decisions	To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered	To partner with the public in each aspect of decision-making including the development of alternatives and the identification of the preferred solution	To place final decision-making in the hands of the public
Promise to the Public	We will keep you informed	We will keep you informed, listen to and acknowledge concerns and aspirations, and provide feedback on how public input influenced the decision	We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision	We will seek your direct advice, recommendations and innovation in formulating solutions and incorporate these into the decisions to the maximum extent possible	We will implement what you decide
Typical Techniques Applied	Fact sheets	Public comment	Workshops	Citizen advisory committees	Citizen juries
	Web sites	Focus groups	Deliberative polling	Consensus-building	Ballots
	Open houses	Surveys		Participatory decision-making	Delegated decisions
		Public meetings			

In our review of over 55 studies, many lacked explicit statements on these participatory dimensions. This omission is problematic given that greater involvement and influence in the decision process is precisely what makes stakeholders interested in participating. Even though it is true that researchers do not always control how participants are involved or their influence on final decisions; it may be that a project's timeframe is too short to observe involvement and influence. None-the-less, researchers should report on the degree of involvement and extent of influence to the best of their abilities. Stating explicit targets for the stakeholder engagement process will both facilitate studies' (self) assessment and help study organizers set clear expectations for all participants. The degree of involvement and extent of influence (Table 2.1) are different from the purpose of participation, which is presented next.

2.4.3 Dimension 5: Goal and purpose of participatory modeling

The main goals or purposes of public participation in modeling can range from simply informing stakeholders to supporting meaningful dialogue that drives the decision-making process. Objectives are also influenced by the unique context of each case. Models cannot be expected to support processes for which they are not designed; hence, each case should be evaluated relative to its stated purpose. Empirical PM studies show the importance of creating an initial clear purpose, because poorly designed approaches can result in actions that address contradictory objectives [*Dreyer and Renn*, 2011].

Renn [2008] notes that participatory objectives are not consistent among different disciplines and that "conflicts about the best structure of a participatory process arise from overt or latent adherence to one or another concept [or approach]" [2008, p.144]. An anthropologist, economist, sociologist, and/or engineer may have different perspectives on the central objectives and whether they are outcome- or process-driven objectives. For example, in a functionalist economic and engineering approach, the main evaluation criterion is often an improved outcome, such as better water quality. In contrast, in a process-based, anthropological approach, the main objective under evaluation might be an increase in participant diversity, dissemination of empowering knowledge, or improved options for the less privileged. (These might be ends in and of themselves, or they may be believed to be valuable because they contribute to improved ultimate outcomes.) *Renn*'s [2008] analysis provides significant insight into the disciplinary and theoretical underpinnings of: 1) how problems are formulated, 2) who is considered an important stakeholder, and 3) what the objectives and rationales for participation are. These disciplinary perspectives and methodological paradigms impact the objectives of PM. Ultimately a "researcher's perception predetermines which problems are perceived, how they are perceived, and approaches towards the research" [*Prell et al.*, 2007]. Since disciplinary perspectives impact problem definition, "the choice of a modeling paradigm might result in the exclusion of many relevant bodies of learning" [*Hisschemöller et al.*, 2001]. The diverse motivations of different disciplines generate a wide range of participatory efforts which, as stated before, makes it difficult to design standard evaluation criteria for participatory models.

2.5 Stage two: Mechanisms for participatory success

2.5.1 Models as boundary objects

As introduced in Section 2.1 boundary objects are translation devices that sit at the interface of different organizations or groups and act as bridges to facilitate mutual understanding and cooperation [*Huvila et al.*, 2014]. Boundary objects were first proposed by *Star and Griesemer* [1989] to address the "central tension in science between divergent viewpoints and the need for generalizable findings" and to provide bridges for cooperation by essentially translating different worldviews among scientists [1989, p.387]. Maps are often cited as a boundary object since they are easily recognized, and yet convey concrete information (e.g., local fauna, rivers, landmarks) that can enhance communication and facilitate cogeneration of new knowledge [*Star and Griesemer*, 1989; *Cash et al.*, 2003]. Other examples of boundary objects in a collaborative resource management context include spreadsheets and diagrams that allow participants to identify facts and modify seemingly disparate concepts into agreed upon positions [*Fuller*, 2009].

We analyze models as boundary objects in order to identify and evaluate mechanisms by which models can enable participants to converge on an understanding, a vision or a management strategy in water management conflicts. Previous research on boundary objects establishes their role in helping users to 1) establish a shared syntax or language; 2) identify differences, concerns, and relationships clearly; and 3) transform current collective knowledge into agreed-upon facts through discussion, negotiation, and careful scrutiny of what users know [*Star and Griesemer*, 1989; *Carlile*, 2002]. Previous research has shown that boundary objects employ diverse types of knowledge in problem solving [*Star*, 1989], in innovation [*Carlile*, 2002], in cooperation and consensus building [*Fuller*, 2009], and in collective solutions to environmental problems [*Bacic et al.*, 2006]. When applied to sustainability sciences, *Cash et al.* [2003] describe boundary objects as bridges between diverse groups and bodies of knowledge.

2.5.2 Attributes of successful participatory models

In this chapter, criteria are derived from boundary objects research and applied to illustrate a novel approach to the evaluation of participatory models. Table 2.2 summarizes these three criteria. Based on research in the sustainability sciences, *Cash et al.* [2003] provide three metrics of success for boundary objects in public policy, these reflect the boundary objects' ability to convey scientific knowledge: 1) credibility, 2) salience, and 3) legitimacy. While these metrics are derived from characteristics described by *Cash et al.* [2002, 2003], these ideas are also present in the list of intermediate outcomes (referenced as "products of process") given by *Carr et al.* [2012]. In the present study, we expand these characteristics into actual criteria. Each is addressed in the subcategories of metrics that we developed (see below) based on extensive reading of other case studies and their relative success.

Mechanisms are related to intermediate outcomes: they are the means by which those intermediate outcomes occur. Here they are defined as a combination of activities that interact to move a situation from one state to another, in this case, to achieve the desired attributes of credibility, salience, and legitimacy. The mechanisms presented are not intended to be an exhaustive list, but are provided as a descriptive guide. Each criterion is described and justified below, and the five metrics are used to gauge the success of a case study in meeting each criterion.

Table 2.2 Three evaluation criteria further subdivided into fifteen metrics for judging PM success

Critera		Description
Credibility	**C1**	Identifies knowledge gaps, crucial issues, and discrepancies in problem understanding
	C2	Builds shared understanding of facts and language as the starting point for discussions
	C3	Uses data/information derived from trusted sources
	C4	Provides means for stakeholder inclusion in relevant dialogues
	C5	Promotes communication, enhanced credibility and accountability of information, and bridges gaps in new perspectives
Salience	**S1**	Builds effective and frequent communication channels in a two-way dialogue
	S2	Translates information and technology results to address end-user needs
	S3	Incorporates diverse knowledge from a range of users
	S4	Results in a single-text document as an agreement on a set of facts and a platform for co-production
	S5	Helps link relevant questions to end users to answers model can accurately provide
Legitimacy	**L1**	Provides open and transparent criteria for decisions and rules of conduct
	L2	Allows real-time criticisms, feedback and update mechanisms
	L3	Accommodates new information/preferences through model flexibility and acts as educational tool to users
	L4	Analyzes alternative scenarios to create a collaborative environment and converge on solutions
	L5	Elucidates decision process through forum, provides insights rather than "optimal" solutions

The concept of credibility [*Cash et al.*, 2002] is related to the quality of information. Here we develop the idea of credibility specifically for models in the context of PM. A model that fails to capture a system with an appropriate level of accuracy, precision, unambiguity, completeness, and complexity will be judged to be less credible. Discussing a model's credibility will uncover knowledge gaps, identify crucial issues, and reveal any discrepancies in the way stakeholders have defined a particular problem. A model's credibility is based on its contents being derived from trusted sources. If judged to be credible, models can provide participants with a common language for detailed discussions of the system under study, enhance and deepen stakeholders' dialogue, and encourage identification of which information is considered reliable and which is less reliable. We synthesize these considerations into five novel metrics to assess the mechanism for improving the credibility of computer models in participatory process (see Table 2.2, C1-C5).

The concept of salience [*Cash et al.,* 2002] is related to the relevance of information – in this context, information that is provided by a model – to the needs of stakeholders and decision makers. In the context of PM, we assert that a model is salient when co-production between stakeholders and analysts allows stakeholders to use the model to improve their understanding of the system and articulate the questions they want the model to answer. Salient models build effective and frequent communication channels between the stakeholders and allow diverse user to interact. A salient model ideally provides a platform where information can be co-produced by stakeholders and model builders, so that the model becomes a repository for agreed-upon facts, described as a "single-text negotiation document" [*Bourget*, 2011]. Based on our analysis of salience in the context of PM, we propose five novel metrics to assess mechanisms for increasing saliency of models (see Table 2.2, S1-S5).

The concept of legitimacy [*Cash et al.,* 2002] involves participants' trust in the neutrality of information, organizations, and/or processes. Translating the concept into the context of models used in participatory exercises, legitimacy involves participants' trust in the neutrality of model outputs. A legitimate model must be fair in its treatment of stakeholders' opposing views and divergent values, and unbiased in its representation of preferences and interests. Legitimate models provide transparent and clear assumptions. Such models are highly flexible, allowing for real-time changes and feedback, and can easily change assumptions and algorithms. Legitimate models are capable of serving as educational tools for stakeholders and policy makers because they were co-generated with analysts and not constructed in isolation. They also generate insights such as new understanding of the system, not just answers. Lack of confidence in a model by participants is not uncommon until participants can see the potential and value of models as analytical tools. Confidence in a model comes from understanding the process and confirming outputs with intuition or past experience rather than what may seem “magical answers.” We propose five novel metrics to assess the mechanisms for improving legitimacy of models (see Table 2.2, L1-L5).

By establishing fifteen metrics, stage two of our framework transforms the previously identified characteristics of credibility, saliency, and legitimacy into three evaluation criteria that may be used to capture “success.” Success is judged by how well a model increases understanding across disciplines, enables two-way dialogue, enhances legitimacy of decisions, and builds cooperation in its various forms (e.g., consensus, shared vision, end to stalemate). These are components important in building trust, a key factor in institutional cooperation and governance in the Common Pool Resource[10] literature [*Ostrom*, 1999].

2.6 Case studies

[10] Common Pool Resources in economics are goods (often natural resources) that benefit a group of people but cannot totally exclude beneficiaries. They provide diminishing benefit if each individual seeks his or her own self-interest. As a result, common pool resources are different from public and exclusionary goods.

2.6.1 Methods and case selection

Evidence from case studies has several advantages given the depth of insights it provides on the underlying drivers, even though broad conclusions are limited by the small sample size of comparative studies [*Srinivasan et al.*, 2012]. The five cases that follow are not intended to be representative of all participatory model types; the focus is limited to well-recognized, structured, quantitative models within systems analysis methods [*Rogers, 1978; Rogers and Fiering, 1986]*. Of the 55 cases reviewed from the literature, the following selection criteria were applied to choose cases to analyze:

1) Case studies needed to have at least one peer-reviewed research paper published (though, supplementary material could be published, gray literature, internal working papers, or personal communication with authors);
2) Preference was given to real planning studies based on realistic scenarios that made use of a computer model;
3) The set of cases for analysis showed one study representing each of the five degrees of involvement (inform, consult, involve, collaborate, empower),
4) Case studies needed to document stakeholder involvement in enough detail,[11] with reporting that was not limited to model outputs.

The five case studies analyzed met the selection criteria and had a breadth of modeling approaches and diversity in participatory context (geographical setting, stakeholder group size, problem setting, institutional structures, cultural context) that revealed wide variation in the effects we expected to observe among PM approaches.

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[11] Appendix A provides a spectrum on the "Rigor of Evidence" we used to assess the methods presented by the authors to substantiate their claims. Each case is assessed so that the reader can understand the rigor and limitations of the evidence provided.

The discussion of each case study is organized as follows: First, we present background for each case study and a description of the participatory dimensions and model characteristics. Then, we evaluate the relative merits of each model and the summary of the two-stage evaluation based on the evidence provided.

2.6.2 Limitations of the methodology based upon published case studies

This study assumes, as per the premise of IWRM and the laws and regulations identified in Section 2, that inclusive participation is beneficial and desired in resource management. However, while there is no conclusive evidence against participation to suggest outcomes are worse because of it, there is ongoing debate on the value and capacity of participation in resource management [*Lubell*, 2004; *Koontz and Thomas*, 2006; *Muro and Jeffrey*, 2008; *Reed*, 2008].

Our analysis is based on studies published in peer-reviewed journals and on the evidence and assertions presented by the authors. This introduces a bias towards cases that are published, which may be both more likely to have been successful and less likely to present applications of this sort of modeling to real-world decision-making since applied work often goes unpublished. Moreover, a dependence on reports of existing studies also reproduces any biases that may be present in the information as reported by the publication's authors, including those authors' own biases of experience and interpretation. There are obviously incentives to burnish the description of methods and outcomes so as to increase the likelihood of publication and citation; unfortunately, without an objective, third-party evaluation of the process, it is impossible to determine whether the authors resisted those temptations. Published cases are also written from one point of view, which may or may not reflect the opinions of participants. For example, authors' optimistic perspectives on the benefits of participation can influence reporting [*Carr et al.*, 2012].

For most of the case studies, with some exceptions noted in the next paragraph, the conclusions drawn about each case study's participatory dimensions, model effectiveness, and study merit and shortfalls are based upon our interpretation of the authors' self-reports. Most authors did not provide any documentation of surveys or other evaluation instruments administered by them or third parties to the participants and clients of the study that would provide independent confirmation (to a lesser or greater degree) of their self-reports and assertions. Thus, in most cases, we had no basis to confirm or contradict the authors' statements upon which we base this assessment.

Lastly, the papers documenting the case studies selected in this chapter were not prepared for the purpose of our analysis. As a result, some information relevant to our evaluation may be missing or unavailable to us. We acknowledge that this limits our analysis and conclusions, but nonetheless there is a good deal of information from which it is possible to draw some conclusions with confidence. Indeed, the lack of standardized data, documentation, and reporting practices concerning models used in PM is the basic motivation for this study. Conclusions are naturally limited to the three boundary object criteria we evaluated. Despite these limitations, important documented evidence from published case studies provides valuable insights into the mechanisms for tackling real world resource problems [*Srinivasan* *et al.*, 2012]. As will be presented next, the proposed framework provides a consistent and flexible way to derive such insights from a wide variety of studies.

To minimize, to the extent practicable, the above identified biases that result from relying on self-reports and incomplete publications, we searched for additional resources as available. Hence, in addition to the one published paper per case study, other evidence used for these assessments falls under three categories, not all of which were available for every study: 1) self-evaluations in separate papers (published or working papers), 2) third-party evaluations, and 3) direct contact with the authors. Below we summarize the other evidence we were able to obtain for the five studies:

1. The ACT-ACF case study has been the subject of a separate evaluation based on the authors' experience and observations of the case [*Leitman*, 2008; *Leitman and Kiker*, 2015].
2. The authors of the Zimbabwe Forestry, Solomon Islands, and Senegal Delta case studies had conducted separate evaluations of their own work [*Mendoza and Prabhu*, 2002; *Hoverman et al.*, 2011; *D'Aquino and Papazian*, 2014]. The methods used will be noted in each case study.
3. Authors of the Zimbabwe, Las Vegas, and ACT-ACF case studies were contacted for additional information and resources. Through personal communication by e-mail, authors of the Zimbabwe and ACT-ACF case studies provided written documentation of additional reports or working papers that were not available online. No additional information was available for the Las Vegas case study, and it was learned from the study author after repeated requests that no assessment had been done.

2.6.3 Community-based forest management in Zimbabwe

2.6.3.1 Case background

The first case study is a community-based, forest management study in the midlands of Zimbabwe. It combines participation with traditional optimization methods using multi-criteria decision analysis (MCDA) techniques [*Mendoza and Prabhu*, 2005]. Although this is not a water resources study, it was chosen as one of the five case studies for this chapter because forestry shares many similarities with water resources in terms of common resources that require users' cooperation.

Organizers from the University of Illinois Urbana-Champaign held six meetings with district-level government personnel from varied backgrounds who had at least ten years of knowledge of the problem. The researchers led the problem-structuring phase (preference and value elicitation) using cognitive mapping and influence diagrams and the problem-solving phase using MCDA prioritization techniques. The model was not a physical representation of the forest (e.g., tree growth rates) but of the management factors and strategies influencing total revenue.

MCDA was used to obtain diverse participant knowledge, to elicit participant preferences, and to aggregate individual choices to evaluate, prioritize, and aggregate the indicators identified by participants. Soft-systems methods involved the Collaborative Vision Exploration Workbench (Co-View) software that involves a simulation framework for integrating objectives and other components of strategic planning, mainly indicators of

Strengths, Weaknesses, Opportunities, and Threats (SWOT). Co-View allowed for a scenario-based analysis of the problem, giving participants an appreciation for the model's potential as an analytical tool to compare various policies. The authors claimed that participants developed a level of trust for the model, perceiving it as a transparent tool capable of "generating insights rather than magical answers" [*Mendoza and Prabhu*, 2005].

2.6.3.2 Participatory dimensions and effective model characteristics

According to the authors, the *purpose* of the participatory model was to create transparency within participatory processes as a means to build trust, confidence, and integrity in the planning process. More specifically, transparency and trust came from a model built with stakeholders to evaluate openly the cumulative impact of proposed management action plans. Mendoza and Prabhu led the organizing team. The *core participants* were six district-level government personnel, including two district foresters, one agricultural extension officer, one social scientist, and an expert on gender issues who was also a provincial officer.

Participants were engaged in *three stages:* model formulation and structuring, model building, and model use. Participants identified problems, prioritized preferences using MCDA techniques, and quantified process indicators via SWOT. The *degree of involvement* was moderate but the *level of influence* was to "consult" based on the typology described in Table 2.1. The MCDA was used to involve participants' diverse contributions, elicit preferences, and aggregate individual choices. However, absent any statement as to its role – if any – in actual management decisions, the end result is unclear.

In building *credibility*, the analyst began engagement with a free-thinking exercise on cognitive mapping to get stakeholders to frame the problem in terms relevant to them. The group then used the model to narrow the scope. The model allowed participants to iteratively test and discuss how each management plan met agreed-upon purposes and specific goals. The iterative process had two positive effects that improved the model's *saliency*. First, it clarified ideas and helped focus the debate. Second, model runs generated rapport as participants gained appreciation for the trade-offs between goal optimization and costs of executing plans. The low and medium scores were given because despite the title—which proposes a "community-based forest management" – all the stakeholders were government personnel. Consequently, stakeholder inclusion and diverse knowledge, among other criteria, are rated Medium or Low to reflect the limited reach of the participatory process.

The model served as an organizing platform where ideas, opinions, and divergent views were debated and validated by those participating so that the exchange of ideas was mutual and instructive. The plans designed in a collaborative environment proved central to strengthening *legitimacy*. The participants recognized the benefits and value of the model's 'what-if' and 'if-then' features for analyzing policies, because they allowed them to develop a realistic and insightful perspective that built their trust in the model. Scores and evidence for this case study are listed in Table 2.3.

Table 2.3 Score on criteria for Zimbabwe community-based forest management case study

Criteria	Score	Evidence
C1	High	Authors' assertion
C2	High	Article provides evidence

C3	Med	Authors' assertion but limited
C4	Med	Implied, not stated
C5	Med	Authors' assertion
S1	High	Authors' assertion and some evidence
S2	Med	Authors' assertion but implied to be limited
S3	Low	Article provides evidence
S4	High	Article provides evidence
S5	Med	Supplemental material
L1	High	Authors' assertion
L2	High	Supplemental material
L3	High	Authors' assertion
L4	High	Article provides evidence
L5	High	Authors' assertion

2.6.3.3 Evaluation of relative merits and shortfalls of PM effort

Acknowledging the multiple objectives in resource management, this case used MCDA to encourage a systematic arrangement of criteria and decisions by organizing priorities and evaluating the multiple objectives. MCDA quantified each element that influenced the decisions, and generated insight into desirable and undesirable strategies and action plans.

The case study avoided two common pitfalls to optimization, at least partially. First, a common criticism of optimization is that the 'best' optimal solution is determined by an analytical structure that may not fully capture the complexity of the actual problem under investigation. Second, optimization models can be particularly compatible with problems dominated by economic objectives and the assumptions of rational choice theory [*Hisschemöller et al.*, 2001; *Rogers et al.*, 2009]. The authors, hence, adapted the optimization model to prioritize and aggregate options but integrated the modeling process with cognitive mapping to engage stakeholders early on during the problem-structuring phase, and elicited from the participants' assessments qualitative and semi-quantitative indicators.

These adaptations resulted in a mixed model that was useful for stakeholders' purposes and interests since they had contributed to the assumptions of the modeling framework and the criteria by which action plans would be assessed. During the Co-View simulations, decision elements demanded surrogate measures (i.e., quantifiable values) so that improved plans could be judged based on the final management goal of "increased total revenue." MCDA techniques were used to evaluate and eliminate bad choices. That information was combined with the Co-View model that simulated how the chosen criteria affected the ultimate goal of "total revenue" for the community. In this case, stakeholders chose to quantify revenue for community members and compare the model results with the on-the-ground reality – a situation of harvesting with little management that evoked the "tragedy of the commons." The authors recognized that this revenue optimization was a simplification that made the analysis tractable and that using a strictly qualitative final indicator of success would have posed significant challenges. Nevertheless, the integrated methods allowed participants to assess and gain insights into the plan strategies. In the end, with assistance from the model, participants understood the delicate balance between achieving an objective and its costs.

The two-stage evaluation was limited given the insufficiency of the records characterizing this work. The study authors were contacted for supplementary material. They answered our questions and provided an additional working paper [*Mendoza and Prabhu*, 2002] reporting on a valuation process they had carried out with 20 participants after the completion of the initial study. Six core participants responded individually to a set of questions using what the authors refer to as a voting system. Their answers were tallied to derive a hierarchy of preferences. Based on the valuation and on direct contact with a larger group of participants, the authors were able to assert that the intended purpose of building trust through a transparent process had been achieved. Authors also asserted that another observed advantage was the ability to introduce flexibility to balance analytical solutions with other important end-user concerns. However, the documentation and available material lacked specificity about whether the model influenced any management decisions.

2.6.4 Shared Vision Model for the water conflict in the ACT-ACF river basin

2.6.4.1 Case background

The Alabama-Coosa-Tallapoosa and Apalachicola-Chattahoochee-Flint (ACT-ACF) river basins made use of a Shared Vision Model (SVM) as part of a Shared Vision Planning (SVP) process to co-develop simulation models by representatives of federal and state government [*Palmer*, 1998]. To avoid a federal court lawsuit initiated by the state of Alabama over water allocations made by the state of Georgia, the US Army Corps of Engineers (USACE) and the states of Alabama, Florida, and Georgia adopted a Memorandum of Agreement to conduct a $13.5 million, six-year, comprehensive study. A direct consequence of the Comprehensive Study, and its most notable legacy, was an interstate water compact ratified by the US Congress and signed into law by the governors of the three states and the US president.

SVP includes three processes: 1) traditional water resources planning, 2) structured public participation, and 3) collaborative computer modeling [*Bourget*, 2011; *Werick and Palmer*, 2011; *Palmer et al.*, 2013]. The SVM was a systems dynamic model (SDM) built in STELLA that simulated a complex network of rivers and the services they provide, including navigation, flood control, environmental services, and Atlanta's growing water demand from Lake Lanier. Five models were developed and modified over time to improve communication and build rapport between the core participants and the research team. The final model allowed the working group to evaluate and formulate new alternatives. The model's user interface was constructed to allow modification of control variables and parameters. This feature gave participants freedom to formulate, evaluate, and refine alternatives, including combined operating features, which resulted in a new set of options not previously considered [*Hamlet et al.*, 1996].

2.6.4.2 Participatory dimensions and effective model characteristics

The broad *purpose* of the study was to solve a multi-state/federal conflict over water management by identifying innovative reservoir operating policies that met the needs of the region. More specific goals included: 1) create a catalog and repository for important data (hydrologic information, demand/supply data, etc.), 2) characterize the physical features of the basin, 3) document the system's operating policies, 4) evaluate alternatives, 5) illustrate trade-offs between system objectives and seek compromise solutions, and 6) expand the number of people who understand the system's operation.

The models were built by researchers from the University of Washington in consultation with representatives of the states of Georgia, Florida, and Alabama, and the USACE Institute of Water Resources. The *core participants* of the study were members of an Executive Coordinating Committee created for the long-term planning of the interstate watershed, composed of two representatives from each of the state governors and two representatives from the USACE. There was also a separate committee composing the Technical Coordination Group (TCG) composed of four members, one from each of the state agencies and the USACE.

The study was originally commissioned to avoid a lawsuit between the study partners. A memorandum of understanding (MOU) was used in staying the lawsuit, and the participants were engaged in all five *stages of participation* as part of the MOU. This meant that from the problem definition, to data gathering during model construction, to running simulations for model validation, participants were actively engaged in attempting to reach an agreement.

There was a high *degree of involvement* by participants, categorized as collaborative. Initially, the TCG defined large scopes of the work but failed to agree on overarching measures of performance for reservoir operating rules and water allocation policies. Over time, instead of formulating specific reservoir operations, they requested a more flexible SVM that could facilitate the analysis of new alternatives. Participants had very high involvement in model building and could make recommendations, but their *influence* was low since final decisions were the purview of the governors and legislators.

The model was widely accepted as an accurate and *credible* representation of the system, but only after a series of tests to compare the reservoir levels and estimated flows. Comparative tests were conducted between the STELLA model and the HEC5 model previously used. The STELLA model proved to be more accurate and better suited to account for multi-reservoir operating rules. The research team emphasized active participation, incorporating stakeholder critiques in new versions of the model. This resulted in a SVM that was *salient*, and some members of the TCG became skilled in modifying the assumptions of the model in order to answer their questions.

The model was widely recognized for its *legitimacy* among stakeholders. These stakeholders included the primary management agencies and expert consulting agencies such as the U.S. Fish and Wildlife Service and the Nature Conservancy (TNC). Another example of the improved collaborative environment is TNC's effort to develop metrics that supported the ranking of alternative reservoir operating policies making use of the SVM in partnership with researchers at the University of Washington. Table 2.4 provides scores and evidence for the ACT-ACF case.

Table 2.4 Score on criteria for ACT-ACF Tri-State water conflict case study

Criteria	Score	Evidence
C1	High	Third Party Assessment
C2	High	Direct Communication

C3	High	Article provides evidence
C4	High	Implied, not stated
C5	High	Third Party Assessment
S1	High	Internal Report
S2	High	Third Party Assessment
S3	Med	Internal Report
S4	High	Compact signed
S5	High	Internal Report
L1	Med	Third Party Assessment
L2	High	Internal Report
L3	High	Third Party Assessment
L4	High	Third Party Assessment
L5	High	Direct Communication

2.6.4.3 Evaluation of relative merits and shortfalls of PM effort

SDMs create platforms for enriching discussion between analysts and users based on visual interfaces that clarify the relationships among variables, alternative future scenarios, and the possible trade-offs. Modern SDMs have evolved from the early 1960s when FORTRAN was the modeling language of choice, to object-oriented environments (e.g., STELLA, POWERSIM, VENSIM) and programming languages designed specifically for making dynamic simulations more accessible. Accessibility leads to significant consequences. In this case, dynamic use of the model clarified that, contrary to widespread belief, increasing water use in Atlanta would not substantially reduce base flow to other major rivers (the Flint River). While STELLA is object oriented, it does require basic programing skills. Thus, the STELLA model was integrated with an easy-to-use Excel interface, which allowed stakeholders to participate in characterizing the problem and defining appropriate feedback loops while also tailoring model outputs through Excel.

Much of the information for the ACT-ACF study was accessible through direct communication with the organizing team given my professional collaboration with Palmer and Werick. The case was also the first of its kind in the southeastern United States, and it has been well documented [*Wolf et al.*, 1999; *Leitman*, 2008]. The two-stage evaluation was based on our assessment of supplemental material and on personal communication with the authors. It shows the SVM was not an effective boundary object for its intended long-term management purpose. While the insights generated by the SVM built consensus, the process also managed to insulate the core participants from influencing decisions because their role was seen as advisory rather than decision-making. The model was effective in achieving the more moderate research goals. Despite some initial resistance, the SVM modeling platform contributed to improved dialogue as core participants engaged in repeated testing of hypotheses and virtual experimentation, making the SVM widely trusted. To some extent, the SVM is still used today [*Leitman*, 2008; *Leitman and Kiker*, 2015]. Although participants joined to determine a common purpose, the effort did not anticipate that the interstate Compact would establish water allocation agreements outside the Comprehensive Study, effectively turning the core participants into mere advisors who were unable to decide or execute plans when key actors and political tides shifted.

2.6.5 Water management alternatives in Las Vegas, Nevada

2.6.5.1 Case background

The third case study is the development of a model to evaluate alternatives to extend the life of the water supply for the city of Las Vegas [*Stave*, 2003]. The research team developed an

SDM to compare the relative merits of different policy options. The SDM engaged participants and allowed them to re-evaluate the starting conditions or change their preferences in an open exploration of policy options. During ten workshops the team tested the effectiveness of the SDM. Different alternatives for water conservation (indoor/outdoor use, hotel use, etc.) were modeled, and, as the stakeholders gained confidence, they made suggestions on new hypotheses to test. The results provided several insights counter to stakeholders' intuitions. For example, casino and hotel water use was not as significant as residential use, and small changes in per capita demand were as effective as large supply increases.

2.6.5.2 Participatory dimensions and effective model characteristics

The primary *purpose* of the model was to test the effectiveness of an SDM to support stakeholder learning and discussions but was not intended as a decision support tool. During workshops, participants were engaged in evaluating the relative merits of extending the year in which demand would outstrip supply (denoted as the "crossing-point") based on the given policy options available.

The study organizers included researchers at the University of Nevada, Las Vegas in consultation with the Southern Nevada Water Authority and the U.S. Bureau of Reclamation. The *core participants* were recruited for research purposes and comprised 83 community members and residents who ranged widely in age and profession. The author does not report the selection criteria for participants. The *stages of participation* were compartmentalized. In the first two stages, experts provided data and defined the problem, but they did not take part in the subsequent workshops. Then, participant groups were involved in model validation and analysis of acceptable policy options. All ten workshops featured different participants each time.

The *degree of involvement and extent of influence* in this case study were intentionally low. The degree of involvement falls in the inform category, given that the workshops were two-day events that featured new attendees each time. This is in contrast with other case studies presented, which attempted to maintain the same core participants throughout the duration of the study. Participants were engaged in the later stages of the model's use to learn about policies that changed future demand/supply outcomes. The model thus served as a tool for communicating with the public, and the participants' engagement was not intended to change any policy decisions.

The model built *credibility* by providing a shared language and starting point for discussion. However, it was not inclusive because it did not reflect stakeholders' engagement in problem definition or in alternative generation. The model demonstrated poor s*aliency* because its design did not allow participants to apply their knowledge in defining alternatives or addressing questions/problems relevant to their specific situation. Instead, participants were given a predefined problem to solve and five policy options to solve it; two options were new alternative supplies and three options addressed water demand reduction or conservation.

The simplicity of the model contributed to its *legitimacy*: participants quickly grasped the effects of changing parameters, trade-offs, and policies to move the supply/demand crossing point. The model's success in building legitimacy was self-reinforcing. As participants gained confidence, trust in the usefulness and results of the model increased and fueled greater interest and engagement from participants. When the model challenged their views on the problem, they saw this as an incentive to ask more questions and make new suggestions. Legitimacy was reduced, however, by the inability to introduce stakeholder-designed alternatives. Scores and evidence for the Las Vegas case study are provided in Table 2.5.

Table 2.5 Scores on criteria for the Las Vegas water management alternatives case study

Criteria	Score	Evidence
C1	Med	Author's assertion
C2	High	Article provides evidence
C3	High	Author's assertion
C4	Low	Author's assertion
C5	Med	Author's assertion
S1	Low	Direct Communication
S2	Med	Direct Communication
S3	Low	Article provides evidence
S4	Med	Author's assertion
S5	Low	Article provides evidence
L1	High	Author's assertion
L2	High	Article provides evidence
L3	High	Article provides evidence
L4	High	Article provides evidence
L5	Med	Author's assertion

2.6.5.3 Evaluation on relative merits and shortfalls of PM effort

Simulation models are favored in stakeholder engagement because of their ability to co-validate model building and to structure and improve the content and timing of discussions

[*Jenkins-Smith and Sabatier*, 1994; *Dwyer and Stave*, 2008]. Several SDM platforms use object-oriented environments and are more visual in nature. These effective characteristics of simulation models have led to their growing application in resource management. Such studies include *Nandalal and Simonovic* [2003] who use system dynamics in water conflict resolution for a hypothetical collaborative decision-making case; *Palmer et al.* [1999] on river-basin planning; *Stave* [2002] on public participation in transportation and air quality management decision making; and *Bolson and Broad* [2012] on a South Florida regional water management model. *Winz et al.* [2009] present an in-depth review of theoretical and practical developments of SDMs in the past 40 years, which, along with other cited authors herein, suggests that SDMs are particularly suitable for stakeholder participation and represent a favored method among analysts.

In the Las Vegas case, participants were presented with visuals of the decision variables, parameters, constraints, feedback loops, and outputs that enriched the discussion. Stave suggests that the model altered the participants' understanding of the fundamental drivers of water conflicts. Participants were surprised with the finding that solely increasing supply was not the best policy option. The simulations provided several counterintuitive results that made for lively discussions. Consequently, the opportunity surfaced among participants to reconcile their disparate starting assumptions and to become receptive to possible solutions that were not deemed acceptable before.

Supplemental material for the Las Vegas case study was very scant. The author was contacted to verify the assertions that were made in the article. It took several attempts to get a response: the study had been a pilot study with Nevada State authorities and there was no follow-up evaluation. Consequently, all conclusions drawn here are based on author statements in the original article.

The two-stage evaluation shows that the Las Vegas SDM was able to achieve its modest purpose, but any larger impact was limited by a narrow scope of engaging participants in a proof of concept. Our conclusion is congruent with follow-up communication with the author. The primary published paper states explicitly that participation in the modeling process was opened to community participants at the last stage of policy analysis and not in earlier stages such as problem definition or model construction. The goal was to inform participants by engaging them in the modeling effort to understand how different policies affected the crossing-point of demand and supply. The model's simple and intuitive nature helped participants understand the problem of demand/supply from a new perspective and appreciate the results even when they did not align with their own paradigm. The author attests to this new appreciation and understanding to the model. We find evidence in support of this assertion in the participants' ability to engage and in the fact that they proposed new testing scenarios in real-time, which implies that they had developed some understanding of the system. While the model was credible, participants had no influence on decisions or policies, and experts rather than stakeholders determined the relevant model and the policy options. Thus, the legitimacy and saliency were affected.

2.6.6 Water resource allocation in the Solomon Islands

2.6.6.1 Case background

In the Solomon Islands case, local managers of the Kongulai water catchment made use of a water resource allocation model constructed to support decisions [*Chan et al.*, 2010]. The catchment is approximately 50 km^2, is located upstream of the capital city Honiara, and provides about 60% of the capital's water supply. Study participants included landholders, local government officials, and donor and non-governmental organizations. There was a history of conflict between the clans living in the catchment and the Solomon Island Water Authorities (SIWA), including protests over inadequate or late royalty payments and sabotage of the water infrastructure by the landowners. SIWA's past community engagement efforts were limited and unsuccessful. Over the two-and-a-half-year study, the research team engaged participants in an inclusive and culturally sensitive manner to avoid resurfacing of past tensions.

Stakeholder groups were first invited to participate separately to describe their challenges. The research team used these descriptions to build conceptual diagrams which participants reviewed before analysts built the Bayesian model. Emphasis was initially placed on problem formulation. Then, a Bayesian Network (BN) was used to generate and analyze defensible scenarios informing catchment management planning. Five months later, a small representative group of participants (about one third of original group) met for second time to edit, verify, and comment on the final BN. The organizers recruited a cultural guide to facilitate workshops. Also, to be culturally sensitive and promote inclusion, several of the workshops were divided into groups based on clans and gender.

2.6.6.2 Participatory dimensions and effective model characteristics

The *purpose* of this study was to improve information and data collection on water use so as to prioritize potential management actions. The model was not intended to address negotiations over previous conflicts regarding resource royalty payments. The project was organized by researchers from two different Australian Universities in collaboration with the Solomon Water Authority, the Australian Water Resources Facility, and the AusAID research initiative within the International Water Centre. The *core participants* included community landowners (two sub-clans living within and below the catchment area), government agencies, and donor and non-governmental organizations. A cultural guide who also served as an interpreter was recruited to help conduct the participatory research within the appropriate context.

The *stages of participation* in this case were fragmented. The first stage emphasized engaging participants in building conceptual diagrams based on their problem definition. However, to avoid the resurfacing of past tensions, stakeholder groups were engaged separately by local community representatives, government representatives, and donor and non-governmental organizations. Subsequently, the diagrams were merged to build a BN. Then a smaller, yet representative, group of participants was asked to join in a second iteration for editing, verifying, and commenting on the final BN model.

The *degree of involvement* can be generally characterized as involved, in general, with some groups invited to be collaborative given the level of information elicited from those participants. Participants were engaged to define important stages like establishing the problem and "common terms of reference", and, for a smaller group, evaluating policy alternatives. This case study was different in how it involved stakeholders in a more fragmented manner, effectively separating who was involved in model inputs and outputs. As a result, the extent of *influencing decisions* is different for managers and all other stakeholders. Managers were expected to remain with the model after the research team left, so their engagement and influence was important. The model enabled managers to prioritize interventions. The same influence cannot be stated for the community groups and NGOs; they used the model at a conceptual level as an information tool rather than a decision tool.

The deliberate inclusiveness in the early stages positively impacted the c*redibility* of the model. Despite past acrimonious relations, diverse stakeholders were able to engage in constructive dialogue and establish common ground on the facts. The fragmented nature of the stages of participation, however, left some doubts about the extent of inclusion of participants in relevant and influential dialogue later on.

Saliency was judged on how well the model captured diverse knowledge and relevant questions. In this respect, the ability to bring people together to communicate and agree on facts showed that given the right environment and platform, participants found common ground to overcome differences to collaborate in new and unexpected ways.

The model's *legitimacy* also ranked high in most criteria, since providing transparency and accountability in the process improved relationships. The model created a "shared vision" over water plans and played a role in establishing interventions and priorities in infrastructure, making catchment and supply management decisions, and, to some extent, influencing the behavior of the water users. These positive participant relationships reinforced themselves and made the modeling effort more legitimate. Table 2.6 provides scores and evidence for the Solomon Islands case.

Table 2.6 Scores on criteria for the Solomon Islands water resources allocation case study

Criteria	Score	Evidence
C1	High	Article provides evidence
C2	High	Quotes from interviewees
C3	High	Authors' assertion
C4	Med	Implied, not stated
C5	High	Interviews
S1	Med	Interviews
S2	High	Article provides evidence
S3	High	Assertions and interviews
S4	Med	Provided evidence and interview
S5	High	Interviews
L1	High	Description
L2	Med	Implied, not stated
L3	Med	Interviews
L4	High	Interviews
L5	High	Interviews

2.6.6.3 Evaluation of relative merits and shortfalls of PM effort

BN modeling has found many applications in participatory ecological risk assessment because of its graphical representations and its ability to integrate stakeholders' conceptual diagrams of the problem definition. *Castelletti and Soncini-Sessa* [2007] and *Uusitalo*

[2007] provide other examples of BN modeling in environmental applications. BN models are graphical models that represent probabilistic systems operating under uncertainty. They have the ability to automate probability updates with new observations, providing improved model accuracy with new iterations. Another advantage is the low formal data requirement of BNs, which makes them suitable in data-limited contexts like this one. In this case study, the limited availability of data, the high uncertainty, and the initially incomplete understanding of the system persuaded researchers to use a BN model.

Initially, a "staged knowledge-building process" was used to elicit knowledge and views from participants, which were later combined with quantitative data about the physical characteristics of the catchment area. The concept diagrams developed separately from different groups and perspectives were later merged to create one comprehensive network diagram. In subsequent sessions, the analysts introduced perspectives from previous groups for comparison and to underscore common views. This step proved to be a significant challenge; however, once progress was made in individual groups, the groups were reunited in a follow-up session to simplify the model within smaller representative subgroups. In the final workshop, a small group of water professionals with technical backgrounds was summoned to determine the initial conditional probabilities. The model was crucial in creating a single-text document agreeing on the set of facts. However, the fragmented nature of participation left unclear the extent to which all representatives influenced decisions in later stages.

The two-stage evaluation showed that BN modeling effort was successful at meeting its purpose of enabling managers to prioritize interventions. A separate publication [*Hovernman et al.,* 2011] by the authors that evaluated the participatory effort provides several examples and direct quotes as evidence of their success. The benefit of the participatory model showed that it was possible to bring transparency and accountability to the process, resulting in improved credibility and legitimacy of the model. Though not an original study goal, an independent forum composed of the same participants came together to deliberate on logging issues indirectly related to water. Government agents facilitated the forum and requested model outputs prior to making decisions. The unexpected outcomes of the study (i.e., the creation of an independent group that used the model for other deliberations) are a testament to the saliency and legitimacy brought by the model building process, whereby people learned to work creatively and collaboratively in new and unexpected ways.

2.6.7 Regional planning in the Senegal River Valley

2.6.7.1 Case background

The fifth study was set in the Senegal River Delta and applied the Common-pool Resources and Multi-Agent Systems (CORMAS) modeling platform that had been previously developed by the CIRAD Center (*Cooperation Internationale en Recherche Agronomique pour le Développement*). CORMAS uses direct and extensive stakeholder engagement workshops [*Le Page et al.*, 2012] and provides a framework for developing simulation models of cooperation among agents and institutions that manage Common Pool Resources (CPR) [*Bousquet et al.*, 1998]. The CORMAS modeling tool arose from a rich literature developed by CIRAD researchers in the 1990s [*Le Page et al.*, 2012]. In the most cited

CORMAS case study, *D'Aquino et al*. [2002] used a modeling platform to integrate participants' knowledge and stimulate collective learning by having participants build a "shared" model of land-use problems and possible solutions. Three study sites spanning 2,500 km^2 and with a combined population of 40,000 in the Senegal River Delta made use of role-playing games and an agent-based model (ABM) to develop sustainable land-use management strategies.

Model-building took two years and involved several three-day workshops with local communities. The entire project spanned 10 years. Local community representatives (i.e., farmers, hunters, fisherman, breeders, etc.) and public institutions were engaged in several workshops led by the CIRAD team. Researchers allowed stakeholders to play the role of an agent (e.g., farmer, breeder, etc.) who could actively deliberate and decide on each stage of the model building process (e.g., fisherman focusing on fishing). In later planning stages, role-playing games were modeled and made into an ABM with geographical information systems (GIS) tools. The ABM provided quick and systematic assessments of management options, while GIS created a visual representation of input and output data. The self-design process elicited from participants the most crucial elements and stakeholders to include in the analysis, and they identified the incentives, constraints, and challenges faced by each stakeholder. This consensus meant that later in the process these elements would be more difficult to contest when tensions or conflict over actions escalated. As stakeholders designed new self-governing rules for monitoring and regulating, access to and use of resources was more widely understood.

2.6.7.2 Participatory dimensions and effective model characteristics

The *purpose* of participation was to create autonomous and empowered communities that could improve land-use planning by means of stakeholder-driven, bottom-up simulations of decisions and self-governing regulation alternatives. CORMAS' programming language is object-oriented, and it creates visual models to improve the use, access, and transfer of technical information in land-use problems. Organizers included the CIRAD research team in collaboration with one rural community council. The intended *core participants* were public institutions and local community representatives, including farmers, hunters, and fisherman, all from various ethnic groups.

Since this model was a self-designed model, the stakeholders were engaged in all five *stages of participation.* This included development of the problem definition and model building through the role-playing games, as well as model validation and use during scenario based analysis. The *degree of involvement* was characterized as high with goals of empowering participants to make decisions and self-govern over agreed upon rules. However, the *extent of influence* was moderate and small-scale at first. The community felt empowered to design and regulate their own land-use rules. In later years, community members had the ability to create and negotiate land-use plans. Eventually, an assessment carried out a decade later showed that even these small successes led to the adoption of self-design models (e.g., CORMAS) for other national level projects and laws.

Credibility was judged high based on the consensus built through the modeling efforts. The stakeholder meetings and self-design model resulted in a formal proposal, drafted based on model results with agreed-upon recommendations and management actions, that acts as a single-text document. The ABM effort built rapport by eliciting locals to share their values, water use, risk tolerance, and risk aversion. Model s*aliency* also scored high based on the ability to translate the modeling platform into an agreement on facts despite diverse knowledge.

Table 2.7 Scores on criteria for the Senegal River Valley regional planning case study

Criteria	Score	Evidence
C1	High	Authors' assertion and photographs
C2	High	Authors' assertion and evidence
C3	High	Authors' assertion
C4	High	Authors' assertion and photographs
C5	High	Authors' assertion and sustained participation
S1	Med	Authors' assertion
S2	Med	Authors' assertion and sustained participaton
S3	High	Authors' assertion and photographs
S4	High	Provided document
S5	High	Authors' assertion
L1	High	Authors' assertion
L2	High	Authors' assertion and photographs
L3	Med	Evidence from Role-playing games
L4	High	Evidence from Role-playing games
L5	High	Authors' assertion

The model's *legitimacy* was judged based on participants' ability to create new rules for access to resources, design innovative collective rules, and organize in order to monitor new land-use regulations. These changes also helped achieve the principle goals of the study. Unique to this modeling platform was the level of autonomy given to participants to determine priorities based on their interactions. This is reflected in the high scores given in credibility, saliency, and legitimacy criteria. Table 2.7 provides scores and evidence for the Senegal River Valley case.

2.6.7.3 Evaluation of relative merits and shortfalls of PM effort

An ABM is defined by an individualistic, as opposed to systemic, approach to modeling. ABMs are composed of autonomous agents, their environment, and the properties that emerge from their complex and dynamic interactions [*Bonabeau*, 2002]. As this case study shows, ABM simulations take advantage of a flexible model structure to create stakeholder-driven, bottom-up modeling platforms. ABM makes no assumptions of "rationality"—there are no assumptions of homogeneous actors, perfect information, or perfect economic efficiency [*Parker et al.*, 2003; *Gerst et al.*, 2013]. Instead, ABMs are well suited to represent heterogeneous and bounded rational agents who are autonomous in their decisions and interactions [*Bonabeau*, 2002; *Yang et al.*, 2009; *Gerst et al.*, 2013]. Also evident from this case is the model flexibility that allows agents' behaviors and environments to be influenced by affiliations, interactions or feedback mechanisms that cause them to learn and evolve. This has made ABM popular in the common-pool resource literature, which embraces more nuanced representations of physical-social interactions [*Bousquet and Le Page*, 2004; *Janssen and Ostrom*, 2006]. These and other characteristics of ABMs have expanded their application in the last 20 years to a wide range of disciplines including anthropology, economics, ecology, engineering, and natural resource management [*Bonabeau*, 2002; *Niazi and Hussain*, 2011].

The flexibility of ABMs is beneficial in answering questions related to the "institutional rules [that] may direct individuals to act in the benefit of the collective" [*Parker et al.*, 2003]. In this project, CORMAS became a tool for exploring collective actions since each participant represented an agent and they learned about the emergent characteristics of effective self-governing institutions [*Ostrom*, 1993, 1999; *Janssen and Ostrom*, 2006]. By engaging participants in a simulation of month-to-month decisions based on alternatives to meet individual needs, the ABM revealed their preferences, risk tolerance, and motives for their decisions, and it allowed the participants to discuss these factors openly. Since ABMs are built from the perspective of agent units, they can learn and adapt through a heuristic decision process. The CORMAS model was used as an exploratory tool to develop a testing technique for alternative hypotheses or candidate explanations. During initial workshops, organizers used the agent unit approach to capture more realistic agent behaviors through role-playing games. Each participant was associated with a constituent unit in the model that made decisions based on needs, preferences, and motives [*Bousquet and Le Page*, 2004; *Castella et al.*, 2005; *Yang et al.*, 2009]. The project's scope, however, was limited by the lack of local technical involvement that left the finished model an orphaned tool. It was unclear who would use it after the organizing team was gone.

The primary research paper provides the authors' assertions about the performance of the process and its outcomes. The paper documents (via photographs, computer model screen-shots, and RPG material) how stakeholders were engaged. We collected additional evidence from two subsequent self-evaluations by the authors carried out 10 and 11 years later [*D'Aquino and Bah*, 2013; *D'Aquino and Papazian*, 2014]. Our two-stage evaluation shows the project purpose was achieved successfully (subject to the caveats offered in Section 2.6.2 about the limitations of author self-reports). Despite an initial moderate level of influence, engagement was sustained in the long-term, and a survey carried 10 years later showed that the model enabled members to build capacity and autonomy in future dealings at regional and national levels. The Senegal Delta study's greatest benefit came from the "dynamic" discussions and "wide-ranging analysis" of collective decisions rather than numerical results. Stakeholders were learning how to manage and self-regulate. The greatest strengths and shortfalls both came from the self-design method. The strengths lay in the autonomous nature of the model that allowed participants to establish the agenda and priorities, providing opportunities for change as new perspectives from other constituents were included. Furthermore, the process generated collaborative solutions that had not seemed viable or favorable before. Conversely, the project's focus on self-design meant that no technical experts were included, and the influence of the project was initially limited and would only manifest many years later.

2.7 Lessons from case studies evaluation framework

Table 2.8 Summary of five dimensions characterizing each participatory efforts and two-stage evaluation

Case Study	Participatory Dimensions Summary	Two-stage Ev
Community-based forest management	**Participants—** ***Stakeholders:*** Six district-level government personnel: two district	Successful: Creation o model using mixed m

in Zimbabwe	foresters, one agricultural extension officer, one social scientist, and one provincial officer who is also an expert on gender issues ***Organizing team:*** University research team and a facilitator	saliency
	Stages of Participation—Model formulation, problem definition and identification, model building and use, model validation by quantifying SWOT and process indicators	Satisfactory: Model w consensus and achievi unclear if or how this
	Degree of Involvement—Consultation and moderate	
	Level of Influence—No indication that any decisions were influenced	Needs Improvement: I record and documenta term benefits of the ef
	Purpose—Broad process goal: reach consensus on action plans based on transparency to build trust, confidence, and integrity in planning process	

Table 2.9 Summary of five dimensions characterizing each participatory efforts and two-stage evaluation (cont.)

Case Study	Participatory Dimensions Summary	Two-stage Ev
Shared Vision Modeling for ACT-ACF water basin	**Participants—** ***Stakeholders:*** Representatives from Alabama, Florida, Georgia, and USACE ***Organizing team:*** University research team and Institute of Water Resources	Successful: The mode core members became assumptions of the mo questions. To some ex today.
	Stages of Participation—problem definition, model construction, data gathering, simulation runs, verification and validation of models	Satisfactory: Effective moderate research goa engaged in repeated vi building trust and salie influence in decisions.
	Degree of Involvement—Collaborative and created new policy alternatives	
	Level of Influence—Advisors had trouble executing plans later on when the politics changed and final decision went to State governors	Needs Improvement: T when political tides sh turned the participants unable to influence de
	Purpose—Support water allocation and new reservoir operation policies	

Table 2.10 Summary of five dimensions characterizing each participatory efforts and two-stage evaluation (cont.)

Case Study	Participatory Dimensions Summary	Two-stage Ev
Water management alternatives in Las Vegas	**Participants—** ***Stakeholder:*** Intended users were residents and community members. Expert opinions were solicited from Southern Nevada Water Authority and U.S. Bureau of Reclamation ***Organizing team:*** University research team in consultation with U.S. Bureau of Reclamation and water authorities	Successful: The simp the model. Participan perspective that allow even when counterintu
	Stages of Participation—Experts were engaged in problem definition, public participants were engaged in model use, analysis, and validation of acceptable policy options	Satisfactory: The moc effective tool that is sa policy process
	Degree of Involvement—Inform	Needs Improvement: stakeholder knowledg outcomes and increasi decisions
	Level of Influence—As a communication tool not intended to change decisions	
	Purpose—Primarily used as a stakeholder learning support tool that allowed them to evaluate the relative merits of different policy options to resolve future problems of demand exceeding supply	

Table 2.11 Summary of five dimensions characterizing each participatory efforts and two-stage evaluation (cont.)

Case Study	Participatory Dimensions Summary	Two-stage Ev
Solomon Islands' water resource allocation	**Participants—** ***Stakeholders:*** Community landowners, government agencies, and donor and non-governmental organizations. A cultural guide and interpreter helped conduct the participatory research ***Organizing team:*** Solomon Water Authority and University research team in collaboration with Australian Water Resources Facility, and AusAID in the International Water Centre	Successful: Creation o collaboration despite p relationships among p thinking on how to be and cultural difference
	Stages of Participation—Fragmented: local community, government representatives, NGOs and donor organizations in problem definition, a smaller representative group engaged in model use and validation	Satisfactory: The mod consensus on a set of f fragmented nature of p questions regarding cr everyone was include later stages
	Degree of Involvement—Collaborative	
	Level of Influence—Government agencies used the model for prioritizing interventions. Model was not intended to resolve negotiation conflicts.	Needs Improvement: landowners and other of model building and
	Purpose— Prioritize management actions and identify competing interests to improve water use	

Table 2.12 Summary of five dimensions characterizing each participatory efforts and two-stage evaluation (cont.)

Case Study	Participatory Dimensions Summary	Two-stage Ev
Regional land-use in Senegal River Delta	**Participants—** ***Stakeholders:*** Public institutions and local community representatives from various ethnic groups ***Organizing team:*** One rural community council and CIRAD research team	Successful: Achieved and building adaptive community members. negotiating agreement

	Stages of Participation—Problem definition developed in role-playing games, model building and validation, and model use in scenario-based analysis	Satisfactory: The dire the modelling effort ar Long-term, it's difficu influence on national l "owned" the model, or anyone
	Degree of Involvement—Empowerment	
	Level of Influence—Local community members created self-governing rules for land-use at small scale. With time it empowered members to create land-use plans	Needs Improvement: dialogue between expe create mutual learning
	Purpose—Improve land use strategies and planning by empowering communities	

provides a summary of the two-stage evaluation process. Four lessons on the mechanisms for model effectiveness are outlined based on the proposed evaluation framework.

First, the effectiveness of the five participatory models, assessed in terms of process mechanisms, was independent of their (diverse) technical characteristics. In practice, there is often a distinction between models for policy and models for science. Models developed by scientists for other technicians are intended for experts rather than stakeholders and are generally more complex, data-intensive, and sophisticated. They are typically judged on their scientific accuracy. Conversely, models in the policy context are intended for a diverse audience and must weigh the benefits of increased complexity against the costs, namely the possibility of alienating non-technical participants [*Webler et al.*, 2011]. They are best judged on their ability to capture scientific facts and render them useful—through mechanisms like those described in Section 2.5.2 – to both technical and non-technical participants. Previous comparative studies indicate that complexity can often obscure transparency, limit model accessibility, and lead to information asymmetries that can undermine the participatory process and support insulated decision-making [*Mendoza and Prabhu*, 2005; *Lemos et al.*, 2010].

Table 2.8 Summary of five dimensions characterizing each participatory efforts and two-stage evaluation

Case Study	Participatory Dimensions Summary	Two-stage Evaluation Summary
Community-based forest management in Zimbabwe	**Participants—** ***Stakeholders:*** Six district-level government personnel: two district foresters, one agricultural extension officer, one social scientist, and one provincial officer who is also an expert on gender issues ***Organizing team:*** University research team and a facilitator	Successful: Creation of a flexibility optimization model using mixed methods to improve model saliency
	Stages of Participation—Model formulation, problem definition and identification, model building and use, model validation by quantifying SWOT and process indicators	Satisfactory: Model was successful at building consensus and achieving purpose, however, it is unclear if or how this influenced anything
	Degree of Involvement—Consultation and moderate	
	Level of Influence—No indication that any decisions were influenced	Needs Improvement: Provide a more complete record and documentation of the short or long-term benefits of the effort
	Purpose—Broad process goal: reach consensus on action plans based on transparency to build trust, confidence, and integrity in planning process	

Table 2.9 Summary of five dimensions characterizing each participatory efforts and two-stage evaluation (cont.)

Case Study	Participatory Dimensions Summary	Two-stage Evaluation Summary
Shared Vision Modeling for ACT-ACF water basin	**Participants—** ***Stakeholders:*** Representatives from Alabama, Florida, Georgia, and USACE ***Organizing team:*** University research team and Institute of Water Resources	Successful: The model was salient and some core members became skilled in modifying the assumptions of the model in order to answer their questions. To some extent the model is still used today.
	Stages of Participation—problem definition, model construction, data gathering, simulation runs, verification and validation of models	Satisfactory: Effectiveness in achieving the more moderate research goals. The model platform engaged in repeated virtual experimentation building trust and saliency; however, it had little influence in decisions.
	Degree of Involvement—Collaborative and created new policy alternatives	
	Level of Influence—Advisors had trouble executing plans later on when the politics changed and final decision went to State governors	Needs Improvement: The model lost saliency when political tides shifted. This effectively turned the participants into advisors who were unable to influence decisions.
	Purpose—Support water allocation and new reservoir operation policies	

Table 2.10 Summary of five dimensions characterizing each participatory efforts and two-stage evaluation (cont.)

Case Study	Participatory Dimensions Summary	Two-stage Evaluation Summary
Water management alternatives in Las Vegas	**Participants—** ***Stakeholder:*** Intended users were residents and community members. Expert opinions were solicited from Southern Nevada Water Authority and U.S. Bureau of Reclamation ***Organizing team:*** University research team in consultation with U.S. Bureau of Reclamation and water authorities	Successful: The simple and intuitive nature of the model. Participants acquired a new systems perspective that allowed them to accept results even when counterintuitive.
	Stages of Participation—Experts were engaged in problem definition, public participants were engaged in model use, analysis, and validation of acceptable policy options	Satisfactory: The model was made into an effective tool that is salient and legitimate in the policy process
	Degree of Involvement—Inform	Needs Improvement: Incorporation of stakeholder knowledge and feedback to improve outcomes and increasing the level of influence in decisions
	Level of Influence—As a communication tool not intended to change decisions	
	Purpose—Primarily used as a stakeholder learning support tool that allowed them to evaluate the relative merits of different policy options to resolve future problems of demand exceeding supply	

Table 2.11 Summary of five dimensions characterizing each participatory efforts and two-stage evaluation (cont.)

Case Study	Participatory Dimensions Summary	Two-stage Evaluation Summary
Solomon Islands' water resource allocation	**Participants—** ***Stakeholders:*** Community landowners, government agencies, and donor and non-governmental organizations. A cultural guide and interpreter helped conduct the participatory research ***Organizing team:*** Solomon Water Authority and University research team in collaboration with Australian Water Resources Facility, and AusAID in the International Water Centre	Successful: Creation of dialogue and collaboration despite past acrimonious relationships among participants. Careful thinking on how to be sensitive to age, gender, and cultural differences to achieve inclusiveness
	Stages of Participation—Fragmented: local community, government representatives, NGOs and donor organizations in problem definition, a smaller representative group engaged in model use and validation	Satisfactory: The model was crucial in creating consensus on a set of facts; however, the fragmented nature of participation left some questions regarding credibility when not everyone was included in relevant dialogues at later stages
	Degree of Involvement—Collaborative	
	Level of Influence—Government agencies used the model for prioritizing interventions. Model was not intended to resolve negotiation conflicts.	Needs Improvement: Inclusion of g community landowners and other stakeholders in later stages of model building and use
	Purpose— Prioritize management actions and identify competing interests to improve water use	

Table 2.12 Summary of five dimensions characterizing each participatory efforts and two-stage evaluation (cont.)

Case Study	Participatory Dimensions Summary	Two-stage Evaluation Summary
Regional land-use in Senegal River Delta	**Participants—** ***Stakeholders:*** Public institutions and local community representatives from various ethnic groups ***Organizing team:*** One rural community council and CIRAD research team	Successful: Achieved the goal of empowerment and building adaptive capacity among community members. Created a single-text negotiating agreement
	Stages of Participation—Problem definition developed in role-playing games, model building and validation, and model use in scenario-based analysis	Satisfactory: The direct short-term benefits of the modelling effort are vaguely explained. Long-term, it's difficult to identify the model's influence on national level policies, who "owned" the model, or how was it accessible to anyone
	Degree of Involvement—Empowerment	
	Level of Influence—Local community members created self-governing rules for land-use at small scale. With time it empowered members to create land-use plans	Needs Improvement: Providing a two-way dialogue between experts and core participants to create mutual learning
	Purpose—Improve land use strategies and planning by empowering communities	

It is clear from the stage two assessments (Table 2.8) that modelers in all five case studies were aware of the need to produce understandable models, although the evaluations of particular sub-criteria suggest that a stronger two-way dialogue between modelers and the public could have improved some of the models. Prior method comparison studies [*Hobbs et al.*, 1992] reinforce our conclusion that how the model is used—the interactions and dealings among participants and model—is as important as the specifics of the modelling method.

Second, models with greater flexibility had enhanced relevance to case study participants, in part because these models evolved to become more complete and sometimes even more complex only as the participants' involvement became more sophisticated; they were thus designed around the decision-making process. Model completeness and flexibility here refer to the factors that were deemed important, and how they were measured and integrated into the model platform; their importance can be clearly observed in the case studies. In the Senegal Delta case, the self-design aspects of the model resulted in a simple and highly flexible model. With each role-playing game, the model was adapted to include new information identified as relevant by the participants. Given the diversity of participants and their limited previous experience with modeling, the use of a simple, self-designed model was crucial to facilitate dialogue. In the ACT-ACF case study, the representatives from each State and the USACE were mid- to high-level water managers who appreciated increased accuracy and completeness despite its accompanying complexity, provided that the model captured system nuances. As managers' understanding of the system improved, so did the model's relevance, and they requested greater sophistication to address their specific questions. The evaluation criteria show the balance between completeness and flexibility as these two characteristics relate to the mechanisms of relevance and credibility. The importance of this balance is consistent with the observations of *Palmer et al.* [2013] that the key to relevant models is to engage participants throughout the modeling process, continually focusing on "Who will use the model" and "How will it be used to make decisions?"

Third, the inherently interdisciplinary and largely non-technical tasks of PM – identifying stakeholders, selecting participants, defining the capacity and extent of stakeholder involvement, and structuring the participatory process—will affect the ability of the model to build credibility, saliency, and legitimacy. Participants' interactions (e.g., consensus, trust, information exchange) are highly sensitive to group representation and size. It might be asked whether modeling is more effective in the context of smaller or larger groups, or whether there are ways to structure (larger) groups in order to better use models. The case studies suggest that a balance must be achieved between establishing a broad representative group and finding a group size that enhances coherent and productive dialogue between participants. The evaluation highlights the nature of this balance. In Zimbabwe, six representative participants ensured a quick and efficient model building and engagement process. However, it is unknown whether the PM effort influenced any decisions and, therefore, whether the model, however effective, was anything more than an exercise with no real consequences. Conversely, the Solomon Islands case study engaged more than 99 stakeholders, but due to past social conflicts, workshops were initially held separately. This resulted in more inclusive participation and provided a culturally sensitive environment associated with age and gender roles. It was, however, time-intensive, and the authors acknowledged the "unwieldy" effects of large groups in reaching consensus. The cultural specificity of the Solomon Islands case study makes it difficult to infer whether this apparently effective approach of employing smaller subgroups would be transferrable to other contexts. The evaluation shows how model effectiveness in improving scores across all legitimacy, credibility, and saliency criteria is highly dependent on the working group size and how size influences the dynamics of group interactions.

Fourth and finally, the boundary object lens of the evaluation framework reveals how the computer models themselves – as distinct from group facilitation, mediation, or other participatory techniques – can catalyze engagement in negotiation environments. During workshops in the Las Vegas case study, participants accessed SDM outputs to compare the effects of five possible policy solutions to a water resources problem. And in the ACT-ACF case study, the model had a user interface designed to let participants change model control parameters and features themselves. Advances in computing technology like fast computation speeds and the ease with which we can now create and share information in visual or graphic form allow modelers to run scenarios and provide new model output in real time as a fundamental part of the participatory experience. Real-time user feedback has tangible benefits, as it allows changes to model formulation, quick and easy policy trade-off comparisons, and timely deliberations. Advances in computer technology have boosted the ability of models to contribute to the evolving needs of fast-paced negotiation environments that rely on quick information exchange. This is consistent with two findings from the literature. The first concludes that effective science for decision-making allows changes in how problems are defined and framed before providing solutions [*Cash et al.*, 2003]. The second is that models can be central to creating negotiated solutions from participants' dynamic interactions [*Bousquet and Le Page*, 2004; *Dwyer and Stave*, 2008]. The cases provide evidence of modeling platforms that transform water negotiations to support policy as a process that is debated rather than policy as a prescribed outcome.

Comparing five case studies allows for some generalizations regarding the success of PM. An important question is whether different types of computer models (e.g., ABM, MCDA, SDM, BN, etc.) are more or less useful to participatory modeling. In our review of the literature, there is no one model that lends itself better to participatory processes than the others. In fact, agent-based modeling, one of the most complex approaches and among the least likely to be found intuitive, proved to be very effective at engaging Senegalese farmers and fisherman (i.e., people least familiar with computer models). In the Senegal case study, organizers defined the purpose as creating "autonomous and empowered communities," and by working with the participants and making modeling like a game, they were successful in conveying very complex information. So while there is no winner in the model type field, some approaches to PM are more effective than others when they take advantage of process mechanisms like those we have outlined.

This factor is related to another key factor in model effectiveness; effort. Cases that scored high were also projects where engagement was sustained for longer periods (ACT-

ACF, Solomon Islands, and Senegal Delta). It can be inferred that sustained effort contributes to creating shared purpose and genuine dialogue—factors that are often written off as "intangibles" but are in fact important to PM success. In short, the more effort invested in getting participants to incorporate models in their thinking so that it becomes a tool for communicating, the more effective the model. Projects that defined their purpose in more limited terms (e.g., the Las Vegas project, whose purpose was to inform) could reach their objectives but still be assessed medium or low in achieving saliency or credibility. The reason is because the limited goals meant there was no opportunity to test how effective the PM efforts were in building participants' ability to use model information to influence resources management.

2.8 Summary and conclusions

Over the last 30 years, changes in "traditional" WRM models have opened a debate among experts about how to create a more accessible modeling paradigm that is transparent, flexible, timely, and relevant to the needs of a diverse public [*Loucks and French*, 1985; *Rogers and Fiering*, 1986; *Lund and Palmer*, 1997; *Simonovic and Fahmy*, 1999; *Mendoza and Prabhu*, 2005]. Traditional WRM models lacked the "explicit recognition of various interests and pressures [that] are part of the process used to generate the alternative candidate" policies [*Rogers and Fiering*, 1986, p.147]. The challenge to improve the efforts that bring greater public participation into WRM remains, both in how scientific/technical information is used and in how stakeholders are engaged to support a democratic discussion about decision-making alternatives. This chapter has presented the role computer models can play in addressing these challenges.

Like traditional models, participatory models help prioritize management decisions and strategies. However, they cannot be evaluated using traditional criteria for model effectiveness. This study proposed a two-stage framework for assessing participatory WRM models. Synthesizing previously established concepts of participation and boundary objects, the framework provides a structured vocabulary and clear mechanisms that capture the merits of models in participatory and social contexts. These contributions have the potential to help facilitate and standardize design and reporting efforts in future participatory modeling research.

Any comprehensive assessment of the value of PM requires systematic evaluations and comparative studies based on documented evidence from previous trials, failures, and successes. However, data availability is limited and documentation is patchy; indeed, these challenges partially motivated this work. The diversity of efforts in the literature suggest that PM has been dominated by 'trial-and-error' and 'learning-by-doing,' yet as the field evolves and consolidates, standard documentation is needed to improve the practice of PM. The framework we formulated can help structure more complete records and systematic documentation of evidence. Improved record-keeping and documentation would support an higher standard for evaluation and reporting of both future design and concluded PM efforts, while still leaving flexibility in the disciplinary methods used for evaluation (e.g., surveys, interviews, third party evaluations). Our framework should facilitate more systematic comparison across a wide range of PM studies.

Based on the concept of boundary objects, we conclude that models for policy function to create a syntax and common ground in order to build mutual understanding of a problem as a precursor to negotiation. This is consistent with NRC findings that direct interactions between participants increase the effectiveness of future engagements by building on dealings for mutual understanding and trust [*NRC*, 2008]. A boundary object can be the bridge that enables stakeholders to conceptualize new alternatives based on realistic scenarios developed and tested in the model. Effective models can provide an open and transparent platform based on a structured discussion, creating opportunities to change the focus and move beyond conflict towards negotiated solutions [*Dwyer and Stave*, 2008]. Given the right mechanisms and conditions, the iterative process of model-stakeholder dynamics can foster trust, confidence, and consensus.

Finally, this study demonstrates that *process mechanisms* allow computer models to render scientific and technical knowledge useful and relevant to stakeholder needs. Previous literature has focused on final (and to a lesser extent, intermediate) management outcomes to demonstrate the benefits of PM. Certainly, the strength of policy/management outcomes is a legitimate basis for assessment, but outcomes are only half of the picture. Building resource management policies that 'get the science right' requires not only an accurate assessment of facts (i.e., scientific and technical knowledge) but also an accurate assessment of public values (i.e., public knowledge, preferences, and acceptable trade-offs) [*NRC*, 2008]. The participatory process is one of the principles of IWRM, so one might naturally ask whether that process is being embraced and implemented to its full potential, or if natural resource managers are just "going through the motions." When PM is implemented, is it "real"? We argue that prior to an assessment of outcomes, we stand to benefit from considering the mechanisms of the PM process that make those outcomes possible. Having first identified the challenges of evaluating process mechanisms that facilitate the accessibility and application of technical knowledge (Section 2.2), we proposed a novel two-stage evaluation framework to help identify the divide that can exist between technical solutions and resource management, and we applied it to existing case studies by focusing on the way models were used in the PM process.

The challenges of interdisciplinary research mirror the challenges identified in resource management; building bridges that enable the integration of methods and practices across diverse disciplinary lines is not easy [*Ledford*, 2015]. The literature suggests that policy decisions are most effective when people have been engaged early and frequently in the discussions and can understand the benefits and risks involved [*NRC*, 2008; *Posner et al.*, 2016; *Werick et al.*, 1994]. Participation in model building is one platform for those repeated engagements. The processes of building institutional capacity and strengthening water governance are an outcome of repeated engagement, a form of "democracy in action." They allow private individuals to become public citizens who are engaged in developing policies they find acceptable and binding [*NRC*, 2008].

CHAPTER 3. CHRONICLES OF A CRISIS FORETOLD: WATER GOVERNANCE, POWER, AND POLITICS IN SÃO PAULO'S DROUGHT

3.1 Introduction

The following two chapters provide different perspectives on São Paulo's water crisis: this chapter documents the drought event between 2013 and 2015 and explores how it was exacerbated by a convergence of several non-water related events, while Chapter 4 is a technical analysis of system performance and alternative drought plans. The contribution of this chapter is to chronicle and critically examine São Paulo's drought event in order to understand how governance, power, and politics exacerbated a natural event. Although the two public workshops[12] we conducted failed to build collaboration between crucial decision-makers, the workshops contributed insights for our present analysis of institutional barriers to increased participation and governance in São Paulo. The mock participatory model developed and presented at the workshops is also reported here, including an analysis based on the two-stage framework (from Chapter 1) to assess its merits and shortcomings as a boundary object to engage participants.

The case study of São Paulo presented in this chapter shows the limitations of framing water problems purely in terms of scarcity or management. While scarcity and poor management are important underlying drivers, water crises often stem from or are exacerbated by problems in water governance. The case of São Paulo provides concrete

[12] The two workshops described in this chapter arose from the collaborative, academic effort initiated by Falconi in 2013 with Richard Palmer and William Werick for the purpose of together developing and presenting a participatory model in São Paulo. Palmer and Werick made two separate visits to Brazil and participated along with Falconi in the workshops organized at UNICAMP.

evidence of how political interests can sideline technical know-how, models, and plans, even co-opting technical information and jargon to obscure the severity of the problem. This case study illustrates that participation in water resource management is far more complex than just having a seat at the table, and that even the “best-conceived” systems can go awry due to several technical and non-technical factors. Beyond São Paulo, this case study reveals the many contradictions that exist within the internationally recognized and widely used framework of Integrated Water Resource Management (IWRM).

As discussed in Chapter 1, IWRM has emerged over the last two decades as the new international paradigm for managing water, with an emphasis on effective governance. IWRM was highly influential in Brazil’s water reform process, and many Brazilian experts were active participants in promoting IWRM’s ideals in water management. The IWRM paradigm emphasizes the importance of stakeholder participation in water resource planning. Indeed, it repeatedly invokes diverse knowledge and participation in deliberations as effective tools to deal with competing demands for allocation of water resources. However, the IWRM framework includes some contradictions, and it fails to acknowledge the political nature of water resources. These shortcomings, which have been explored by other scholars [*Biswas*, 2004; *Conca*, 2006; *Molle*, 2009], are central to the São Paulo water crisis.

3.1.1 A crisis in São Paulo

The metropolitan region of São Paulo (MRSP) and neighboring regions experienced the worst drought in recorded history starting in 2013, placing some 21 million residents at risk of water shortages. From some perspectives, the explanatory factor in São Paulo's drought may appear to be lack of planning, while others explain the lack of rainfall as an extremely rare (climatological) event [*Braga and Kelman*, 2016]. However, these framings of the crisis are narrow and simplistic, leaving out a great deal of the evidence. This case study illustrates how water allocation decisions are fraught with political questions of who gets what and when, and it reveals the extent to which underlying institutional challenges (e.g., who has access to technical information) drive water conflicts. Recognizing how technically-informed solutions and existing plans can be sidelined by information asymmetries, by the use of technical jargon to obscure information, and by the timing and light in which facts are presented reveals key impediments to the participation of specific stakeholders. Rainfall eventually eased the drought conditions in São Paulo, but not before water governance (based on IWRM principles) had been undermined. This chapter explores this drought event, including several layers of social and political unraveling, to chronicle what masked early and urgent warnings of the impending crisis.

In an interview titled "Living Dangerously," Fernando Reinach pointed to São Paulo's insatiable thirst, which caused an endemic crisis that had been growing for decades as demand outpaced supply, and to a tendency by authorities towards "living dangerously" by ignoring the problem [*Safatle*, 2015]. Reinach is no stranger to São Paulo's water conflicts, which have been ongoing for decades. His father was the president of the state-owned water utility company, SABESP, in the late 1970s, and the SABESP headquarters building is named after Reinach senior. Since childhood, Reinach has watched the progression of the Cantareira system from a major engineering feat to the dire circumstances of 2015. Reinach holds a Ph.D. from Cornell University, is a member of the Brazilian Academy of Science, and was once the Secretary of Science Development at the Ministry of Science and Technology. He calls the drought the "last drop" that triggered the water crisis. In the midst of the drought, Brazil made newspaper headlines as the eyes of the world turned to watch how the country would deal with the confluence of several issues: preparations to host the 2014 World Cup, mounting signs of an economic slump, and the start of a highly competitive presidential election. All of these happenings placed Brazil and its politicians under a magnifying glass on the world stage. Public and external perception of the facts took on new importance, and masking the severity of water resources problem seemed like an acceptable policy to those in charge, despite what was at stake.

3.1.2 Objectives and methodology

Given the magnitude and severity of the problem, I initiated an academic collaboration in 2013 with Richard Palmer and William Werick, coauthors of the U.S. National Drought Study (1995) and collaborative modeling experts who pioneered the method of Shared Vision Planning. I sought their collaboration to engage Brazilian academics and facilitate two public workshops that were held over a period of 10 months at the University of Campinas (UNICAMP). The objective of this multi-institutional collaboration was to demonstrate what an open and transparent dialogue (with the use of a participatory model) would look like if applied to São Paulo's water conflicts. The objective of this chapter is to summarize and report the results of these workshops and to analyze the obstacles to building collaboration around solving the water conflict. While both workshops drew significant attendance (more than 150 diverse participants each), they suffered from the absence of certain well-positioned stakeholders who were responsible for making major water decisions and who entirely circumvented existing platforms for deliberations. Efforts over a year and a half to engage the SABESP water utility and state water authorities failed. During this time period, the drought worsened and water supply deliveries were reduced by more than half. Here, we analyze the state water authorities' response to the drought.

This chapter makes use of a mixed-method approach that includes interviews, meeting attendance, and content analysis of technical documents. I conducted a total of 33 semi-structured interviews with water expert participants and local stakeholders between 2011-2015 during separate research trips to Brazil. Another source of information came from my attendance and participation in over two dozen water basin and water permit renegotiation meetings from August 2013 to December 2015. Interviews and meeting attendance help triangulate information and identify the discrepancies between written documents and management actions. Appendix B provides a methodological note on the interviews conducted and the roster of meeting attendance. Appendix C provides a sample of the open-ended interview questions approved by the Institutional Review Board.

Information gathered through interviews and meeting attendance was complemented and contrasted with that obtained through contact with key informants, document review of technical reports, and observations in two different online discussion groups between 2013 and 2015. My document analysis involved mining a range of document types (e.g., decrees, reports, resolutions, etc.) for information including performance metrics (e.g., reliability), definitions (e.g., water banks) and regulations (e.g., primary vs. secondary flows) that pertained to the operation of the Cantareira system. The online groups included a public forum (São Paulo's Water Crisis Forum) and a national expert forum (Brazilian Water Resources Association online forum), both of which actively discuss water resource concerns.[13] Lastly, quantitative methods were used to develop a mock participatory computer model called the Shared Vision Model (SVM), which is described in the workshop interventions section. For an application of this model to analyze policies for the Cantareira water supply system, please refer to Chapter 4. In this chapter, the SVM computer model developed for the workshops is analyzed in terms of its role as a boundary object for engaging stakeholders.

This chapter is organized as follows: Section 3.2 explains the importance of water governance to understanding this case study. Section 3.3 provides detailed background on Brazil's National Water Reform and argues the importance of São Paulo as a case study region, given its central role in state and national water politics. The trajectory of water conflict between two basins makes this case study region a particularly interesting one. Section 3.4, titled "Anatomy of a Crisis," documents how São Paulo's critical situation –

[13] The Brazilian Water Resources Association online forum fell relatively silent on the topic of São Paulo's drought after Kelman and Braga were named to governmental positions. Many members of the Association were students or colleagues of these two prominent professors, and criticism of the handling of the drought may have become uncomfortable for members.

which nearly caused a water system collapse – happened despite plans and known technical solutions. Section 3.5 documents the factors that motivated us to organize two Shared Vision Planning (SVP) workshops, with an emphasis both on the technical operations of the Cantareira water system and on the role of information asymmetries in exacerbating the problem. Moreover, it provides a discussion of participation, water governance, cooperation, and institutional authority that is grounded in extensive fieldwork, including the workshop interventions. Section 3.6 concludes with some lessons learned.

3.2 The importance of water governance

Water governance is often viewed by technical experts as laws and regulations [*Rogers et al.*, 2009], rather than as a struggle between economics, equity, and the right to decide. While water governance does deal with regulations, it is also the "formal and informal instruments" through which institutions, people, and networks manage water [*Kayser et al.*, 2015, p.187]. River basins are fertile ground for exploring networks of disparate actors who have learned to mobilize necessary resources to bring water into the political agenda and build political support [*Abers and Keck*, 2007].

Social and political scientists point out the importance of competing interests in the struggle to reach a decision – to govern – despite the existence of relevant laws and regulations. We find competing interests present any time water conflicts surface, and Brazil is no exception. One example of particular interest to our current study is the innate tension between technical expertise and decentralized/participatory management that has been woven into the very fabric of modern Brazilian water management.

The Brazilian water reform movement began in the 1970s, and from the beginning it idealized hard science. Hoping to depoliticize a field that had been historically burdened with power struggles, reformists argued that objective, rational, science-based decision-making was the means to find optimal, efficient, technical solutions. This perspective is not uncommon among experts who believe in the attractive promise that technological progress will benefit all without the messiness of political meddling [*Jamieson*, 2000; *Jasanoff*, 2000; *Scott*, 2004]. At the same time, many of the sanitation engineers and other technical experts (*técnicos*) who were important architects and mobilizers of the reforms espoused progressive views on participatory decision-making, and their ideas helped to shape Brazil's new regulations. Even as decentralized, participatory management and institutions were written into law and brought into existence, reformists assumed that planning decisions would be protected from politics by sheer technical competency. Whether deliberately or through naivete, reformers overlooked the inherent contradiction between technical primacy and (meaningful) public participation, ignoring the fact that technically insulated decision-making excludes non-technical actors from participating. Nevertheless, many of the technical experts who had called for more decentralized and participatory management took leadership roles in the newly created agencies and river basin councils [*Gutierrez*, 2010].

But laws, regulations, and a handful of institutions created by decree are not sufficient for water governance; “politics is the arena where changing values of water are fought” [*Rogers et al.*, 2009, p.248]. Experts found the technical ideal challenged when, during the participatory process, policy alternatives were opened to discussion, thus transforming expert ideas and decisions into a subject of debate. Bargaining over technical details was not what Brazilian reformers had envisioned. The new paradigm quickly revealed the inaccuracy of the tacit assumption that “rational” decisions and policies were to remain apolitical in the policy process. Water allocations had always been susceptible to powerful influences, and now there were even more participants at the table. For the Brazilian river basin committees, arrangements on paper for their role in water management became real only as the committees took concrete actions to build political support. This is the process by which small and repeated actions create legitimacy and, over time, power. The term “practical authority” was coined by *Abers and Keck* [2013] to refer to political authority that comes from experience rather than from laws and regulations [*Abers and Keck*, 2006, 2007].

Hence, water governance evolves dynamically but in unpredictable time frames. On the one hand, ineffective participation weakens governing institutions, and participation tends to turn sterile if governance is not exercised. On the other hand, active water governance can strengthen institutions but it demands the kind of autonomy, brokerage, and improvisation that are associated with decision-making power. São Paulo’s water crisis was mostly a governance crisis that can best be understood given the tension that arose between insulating technical decision and who had the power to govern over the water institutions. As we shall see in the next section, the study region had active water-governing institutions as the drought crisis began, yet these institutions failed to gather support to act during the crisis.

3.3 Background on São Paulo's case study

Brazil is a privileged place to study the IWRM framework. Water resources experts in Brazil are not considered "mere recipients of the IWRM paradigm but as active participants in the world-wide, multi-centric process of paradigm change" in water management [*Gutierrez*, 2007, p.84]. The next subsections lay out the importance of São Paulo as a case study region, given its central role in Brazil's National Water Reform and in light of how its history and trajectory of water conflicts have created its existing institutions.

3.3.1 São Paulo as an important case study on the conflicting objectives of IWRM

The river basin committees in the state of São Paulo are among the oldest in the country, and they have decades of experience dealing with civil society in the negotiations of water management. São Paulo's state water laws (as detailed in Section 3.3.2) explicitly called for the creation of the first two river basin committees – the Alto Tietê (AT) and the Piracicaba, Capivari and Jundaí (PCJ) basins – which shared water to supply the MRSP and surrounding regions. The long and contentious dispute over water allocation between the AT and PCJ basins made the region among the most vested in creating decentralized and participatory water laws in Brazil. The PCJ river basin is considered to be at the epicenter of the São Paulo State Water Law, and active members of the PCJ river basin have been prominent authorities in the Nation's water reform [*Castellano and Barbi*, 2006; *Castellano*, 2008; *Abers and Keck*, 2013].

Figure 3.1 Map of Brazil highlighting the state of São Paulo [*TUBE*, 2016]

The state of São Paulo is the most economically developed region in Brazil. The state of São Paulo has historically been the economic engine for Brazil and currently has a Gross Domestic Product (GDP) greater than the next four Brazilian states combined [*IBGE*, 2015a, *IBGE*, 2015b] (Figure 3.1). Together, the MRSP and PCJ region are responsible for 20.9% of Brazil's GDP [*SEADE*, 2011a, *SEADE*, 2011b]. Moreover, the state has a history of established institutions that are soluble, including water institutions. São Paulo is a good testing ground to examine the role of participation and models in implementing IWRM for five reasons. First, it has a longstanding commitment, at least on paper, to IWRM principles dating to the passing of its State Water Law in 1991. Second, there are identifiable sources of conflict between influential regions and between the interests of different stakeholders. Third, the stakeholders in a São Paulo have a reputation for being relatively well-organized. Fourth, there is a large per capita community of well-trained and respected technical water professionals, since the region is home to one of the oldest schools of engineering in the country (*Escola Politécnica da Universidade de São Paulo--USP*) and to several universities renowned both in Brazil and across Latin America (including USP and UNICAMP). Finally, there are well-established water organizations including a water and sanitation authority, water pollution and environmental agencies, and municipal water institutions (detailed in Section 3.3.3).

3.3.2 State and national reform

In the early 1970s, Brazilian water experts and professional organizations, led predominantly by civil and sanitation engineers, participated in international discussion that informed both their vision and the model for the Brazilian water management reform. Interestingly, São Paulo's State Water Law of 1991 (Law 7.633/1991) [14] predated the 1992 Dublin Principles documents that first explicitly expressed the concept of IWRM.

[14] São Paulo State Water Act (1991), Lei Estadual Nº 7.663, de 30 de Dezembro de 1991.

The Brazilian National Water Resource Policy[15] (NWRP of 1997) was passed six years after São Paulo's reform, and it reinforced the central tenets of IWRM. The long and intense reform process involved numerous public debates and workshops, which were seen as central to garnering "strong support for the decentralization process and intensive community participation" [*Porto and Kelman*, 2000, p.254].

Inspired by the French management model, the principles of integration, decentralization, and participation (IDP) were fundamental to the new water management model in Brazil [*Veiga and Magrini,* 2013; *Diz and Soeftestad*, 2004]. The National Water Resource Policy in Brazil interprets the IDP model as meant to: 1) coordinate (integrate) management in multiple uses of water through numerous outlined instruments; 2) decentralize decisions at national, state, and river basin levels that are interrelated, with the river basin becoming the basic territorial unit; and 3) create participation at the level of the *Comitê de Bacia Hidrográfica* (river basin committee, or CBH). The CBH is an innovative, tri-party, representation comprised of state and federal government, public and private water users, and civil society organizations [*Gutierrez*, 2007]. Brazil's stakeholder-driven CBHs were intended to help democratize the decision-making process. The law, in theory, made river basins the territorial unit where decisions were negotiated and debated. It was meant to guarantee that "the negotiation of conflicts, the sustainable use of water resources, and the consequent efficiency and legitimacy of all decisions will be achieved through the participation of stakeholders, that is, all those

[15] National Water Resources Policy (1997), Lei Nº 9.433, de 8 de Janeiro de 1997.

interested in (or affected by) the integrated management of water resources at the river basin level” [*Gutierrez*, 2008].

The idealization of technical knowledge and expertise has been a common theme in Brazil’s National Water reform. The confidence of Brazilian *técnicos* in the technocratic approach came from a long history of authoritarian military regimes in Brazil that spilled over to the planning and policy discourse [*Abers and Keck*, 2013, p.42–43]. The decentralized and participatory management paradigm assumed that technical competency and rational decisions would remain apolitical. Of course, this did not occur. In this case, where *técnicos* played a key role in the reform, their actions were influenced by implicit judgments and worldviews rather than strictly scientific and technical knowledge [*Lemos et al.*, 2012].

3.3.3 Institutional framework

This section introduces some of the institutions in the São Paulo case study. These are federal, state, and basin-level institutions that play a role in São Paulo’s water management. Understanding their relations to the National Institutional Framework (Figure 3.2) helps us determine the institutional functions that were (or were not) executed during the crisis.

ANA (National Water Agency) is a federal agency that was created in 2000 as directed by Law 9984 of 2000. Legislation called for an autonomous Agency that would have links to the Ministry of Environment, but could worked across sectors. ANA has the authority to grant user rights for rivers of federal dominion. Since the Cantareira system has two rivers crossing more than one state and three state rivers, ANA and DAEE share authority for granting rights.

DAEE (Department of Water and Electrical Energy) is the executing agency that under state law is responsible for managing the water resources of state dominion. It grants, licenses, plans, and registers water permits. It was modeled after the Tennessee Valley Authority when it was founded in 1951. Given the history and importance of hydropower in Brazil, its staff is very technical. For decades, it was responsible for the building and technical oversight of hydropower dams in the state.

SABESP (Basic Sanitation Company of the State of São Paulo) is the primary water utility company in the state of São Paulo and supplier to the MRSP. It is a mixed capital company, 50.3% public and 49.7% private, and is listed on the SP and NY stock exchanges. Although it is a state entity, it has been operated as a private company since 1994 (when it entered the SP stock exchange), and it has paid substantial dividends to its stockholders and bonuses to executive officers. High-level positions are filled by gubernatorial appointment, and the technical body is composed of *concursados* (competition-based government positions).

ARSESP (Regulating Agency for Public Service Concessions) is a state agency that regulates, controls, and oversees basic sanitation in the state. Its principal powers are to regulate and supervise sanitation services of both state and municipal ownership. During the drought, it authorized the restructuring of price rates and the "bonus" program.

CETESB (Environmental Sanitation Technology Company) is a state agency responsible for the control, oversight, monitoring, and licensing of activities that generate pollution or affect the fundamental preservation and recovery of water quality. During the drought, they were largely absent from the debates.

CBHs (River Basin Committees, or CBH) are the territorial units in state and federal water laws. The CBH was intended as the planning unit where members would resolve water problems through conflict resolution and consensus building.

The **Water Agency** is the executive arm of a CBH. Despite having access to a rich database, and a great deal of technical expertise, the AT and PCJ water agencies have only played secondary roles in supporting the river basin decisions. Although they have situation rooms for monitoring the basins and are financially solvent, both agencies remained distant from the turmoil of the water crisis.

Though not part of the National Institutional framework, two other entities played an important role during the drought:

MP-GAEMA (Public Ministry) is a government entity at both state and federal level responsible for promoting class action suits in the public interest. The institution's environmental branch in the state of São Paulo (GAEMA) has been very active including organizing public hearings, requesting data through the Freedom of Information Act (Lei 12.527 of 2011), and bringing suits against other public agencies for dereliction of responsibilities. It also negotiates "conduct adjustment agreements" in disputes involving public actors.

CPI (Parliamentary Commission Inquiry) is a commission set up by legislative assemblies at all levels of the federal government charged with investigations that are in the public interest. Similar to congressional hearings in the USA, by law the commission can compel experts and people under investigation to give testimony.

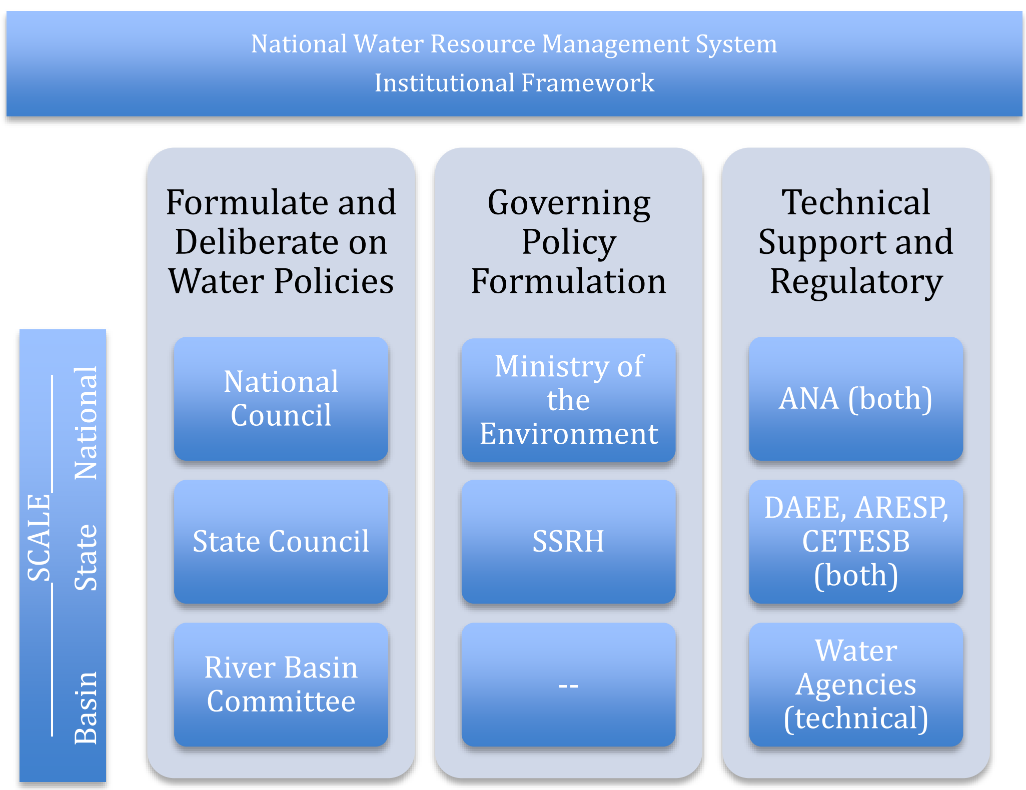

Figure 3.2 Institutional framework for the state of São Paulo's water management system

3.3.4 São Paulo's history of governance and joint management

In this subsection, I examine how governance issues have developed in the São Paulo institutional context. Water stress is not new to the MRSP region. In 2003, a World Bank Report warned of the existing "dramatic situation" in the MRSP given the "serious risks" faced by the city's water supply systems [*Porto*, 2003]. In 2010, a federal Atlas of Urban Water Supply looked at the reliability of water supplies on a 2025 horizon given the physical and economic costs to maintain current infrastructure in the major cities of Brazil. For the MRSP, that figure was R$4 billion [*ANA*, 2011] because supplies would have to be transported from further away to meet the demands of a growing population. An increase in water supply to the MRSP was possible only through a combination of great engineering feats and water transfers from other basins, such as the inter-basin transfer from the PCJ river basins (Figure 3.3).

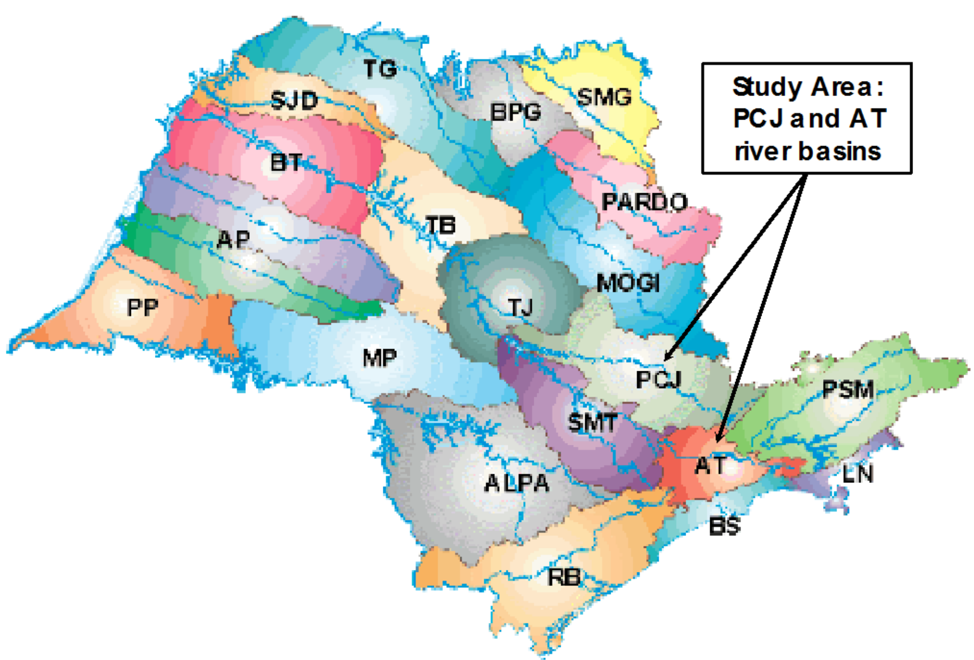

Figure 3.3 River basins units in the state of São Paulo showing PCJ and AT [*CIESP and FIESP*, 2014]

For decades, the PCJ river basins and neighboring Alto Tietê basin, which corresponds very closely with the MRSP, have been involved in a contentious dispute over water allocation. In 1974, the military regime signed Decree No. 750, which authorized the then fully state-owned company SABESP to divert up to 33 m^3/s from the PCJ basin to provide water to the economically booming region of São Paulo. SABESP began diverting water from the PCJ basin because the city's water sources were insufficient to meet its growing demands. Within the 1991 São Paulo State Water Law was a mandate for the creation of the PCJ and AT river basin committees as the first two committees in the state [*Castellano and Barbi*, 2006]. They were created in 1993 and 1994, respectively. The Alto Tietê basin had the resources and motives to become an active and vibrant CBH, as it was expected to resolve the mounting water resource problems affecting São Paulo. However, the CBH-AT struggled to thrive from the start, and its autonomy was undermined as committee decisions were sidelined and members lost interest in participating in activities that did not carry much weight. In practice, SABESP, DAEE, and the State Secretariat of Water Resources and Sanitation crowded out the role of the CBH-AT and acted as negotiator of contracts and permits on behalf of the Alto Tietê basin.

The Cantareira system is an extensive network of reservoirs and tunnels that supply water to roughly half of the population in metropolitan São Paulo. This major infrastructure project along with a 30-year water permit concession was approved during the military government, and the affected municipalities in the PCJ basins resented this fact [*Castellano and Barbi*, 2006]. Conflict over the construction of the Cantareira system began when the water transfer between PCJ and Alto Tietê caused a significant decrease in water quality to downstream users of the PCJ basins [*Seydell*, 2000]. The decades-long battle over water between PCJ, SABESP, and the two state agencies was dubbed the "Cold War" in an interview with José Machado who was past president-director of ANA and among the founders of the PCJ Consortium [*Pereira*, 2016]. PCJ remained dissatisfied with the imposed Cantareira transfer that gave 10 times more water to SABESP than to the sending region after 1975 [*Nunes and Castro*, 2014]. It is under these circumstances that mobilization in the PCJ basin first began to build and shape the institutions that govern there today.

The CBH-PCJ has evolved over time in its functions and form. The first version of the PCJ council was the self-funded Intermunicipal Consortium of the Piracicaba and Capivari river basins, created in 1989. The consortium was the result of intense campaigning and mobilization in the 1970 and 1980s by the municipalities downstream of the Cantareira system to restore the Piracicaba river basin [*AEAP*, 2016]. The PCJ Consortium gained authority and respect as it negotiated between civil society, NGOs, and public and private interests for the basin. Moreover, the PCJ Consortium members' capacity for dialogue and negotiation allowed them to cope effectively through the challenging transition years of the reform, and helped them mature in their technical and political abilities as joint management organizations [*Barbi*, 2007]. They learned to work directly with SABESP and DAEE, and later with ANA, to institute water pricing, the first Water Agency in PCJ, and the first open negotiations of water permits (*outorga*) in 2004.

In 2004, the 30-year concession to SABESP expired, and water permit negotiations to renew allocations took place under new conditions. For one thing, the laws in place had changed. The National Water Agency (ANA) had been created in 2001, and SABESP had been partially privatized, with stock traded on the São Paulo and New York Stock Exchanges starting in 1997 and 2002, respectively. Also, ANA (a federal agency) and DAEE (a state agency) shared regulatory authority over the Cantareira and oversaw water permitting for the basin. During the 2004 negotiations, the PCJ councils were credited with improved negotiating capacities by including diverse players and creating an environment of cooperation, conflict resolution, and compromise [*Barbi*, 2007]. The PCJ river basin committee negotiated heavily and held numerous meetings over the course of 2 years. Despite several concessions, the final PJC document included key conditions that its members considered victories at the time: 1) the new permits were granted for a 10-year period as opposed to a 30-year requested; 2) the legal permit included a commitment and a timeline for SABESP to meet a number of conditions over the next decade (e.g., a signed commitment to investments in sewage collection and treatment over the next 10 years, commitment to reduce water loss, a concrete Macro-metropolis Plan to reduce water dependency from the Cantareira); and 3) the creation of the Water Bank (*Banco de Aguas)* as an innovative management tool to save water for dry seasons or times of need [*Castellano and Barbi*, 2006; *Abers and Keck*, 2013].

3.4 Anatomy of a crisis

The previous section suggests that the history of water governance in Alto Tietê and PCJ make the Cantareira system in São Paulo an attractive case study for adaptive management in the face of critical events. The water crisis provided a clear problem definition. The actors and institutions in the river basins involved were reasonably well-organized and well-informed. Many of the actors knew each other from decades of experience interacting, negotiating, and disputing water issues at local and national levels. And yet when the 2013 drought crisis placed São Paulo at risk of running out of water, the initial response was slow and inadequate given the magnitude of the problem.

In a megacity of the size and importance of São Paulo, there is no simple narrative of the water crisis. São Paulo's water situation had been a growing problem for decades; a lack of rainfall, followed by denial, was what triggered the acute problem. The purpose of this section is to show that framing the problem strictly in terms of water scarcity (limited resources that can be managed better), would ignore a significant amount of evidence on the influence of power and politics. São Paulo's failure to respond promptly to the water crisis makes the region a good case study for highlighting the contradictions within the principles of IWRM.

The remainder of this section focuses on the events that surrounded the drought and water permits negotiations from October 2013 to December 2015. Section 3.4.1 looks at the role of denial and lack of information. Section 3.4.2 show how technical knowledge and technical jargon were used to mask the severity of the problem, ultimately allowing a small group of well-positioned players to shield their decisions from the public eye. Section 3.4.3 explains how the authority of existing agencies was brought into question.

Section 3.4.4 explains some of the complex and competing layers of political interests that were stronger than the existing coalition around the river basin committees.

3.4.1 Denial and lack of information

The drought tipped a long-existing problem into a critical situation. As previously noted, a World Bank report (2003) written nearly a decade before the crisis warned that São Paulo would face water problems. Such warnings were the motivation for the Macro-metropolis Plan to reduce conflict. The Macro-metropolis Plan was an important stipulation in the 2004 negotiations: the final permitting document, Decree 1213[16] Article XVI explicitly stated the need for the MRSP to seek other water sources because its sole dependence on an inter-basin water transfer posed problems for both basins. SABESP presented the original plan of supplies until 2025, called *Plano Diretor de Abastecimento de Água da RMSP* (Master Plan of Water Supply for the MRSP), to DAEE and State government in 2006 but these authorities did not accept it (Meeting #1, September 2013). Instead, a broader, more ambitious study was commissioned in 2008 by the state to map new water sources and demands for a 2035 horizon and in the so-called "macro-metropolis," corresponding to 180 municipalities and about 30 million people. The plan was only completed in October 2013 [*Cobrape*, 2013], several months into the start of the negotiation and the drought event.

Based on our simulation model and analysis of the Cantareira, reservoirs had registered a negative net balance for 22 months (between May 2013 and February 2015). Yet, nearly

[16] DAEE Decree 1213 (2004), Portaria DAEE Nº 1213, de 06 de Agosto de 2004

12 months went by with negative balance before system demands were reduced at the end of March 2014. Moreover, an internal SABESP report dated January 2014, called *Rodízio do Sistema Cantareira 2014* (Rotation of the Cantareira System 2014), provided three restriction plans for dealing with the impending water shortages to avoid what they called "a system collapse" (discussed in Section 4.4.1). SABESP's administration chose to ignore these plans, betting that it would eventually rain. Things would get much worse before their bet paid off.

My preliminary interviews (conducted in 2011 and 2012) and technical document reviews pointed to the robust monitoring network and hydrological simulation models available in the state of São Paulo. As noted earlier, the concentration of technical expertise and university research funding in São Paulo seemed promising for data availability on water quantity and allocations. In August 2013, when I began my extended period of fieldwork in São Paulo, negotiations were underway to renew water transfer permits between PCJ and metropolitan São Paulo. However, I quickly learned of the lack of access to some of the most basic information about the Cantareira system, information that one might expect to be essential for managing water (e.g., inflows/outflows, user permits, pricing). Given São Paulo's wealth and importance, the vast lacuna of data came as a surprise to many. For example, in an interview with two ANA *técnicos*, it was revealed that ANA did not have direct access to monitoring stations in the Cantareira. Only after an incident of misreporting did ANA have a *técnico* from the Situation Room assigned to monitor SABESP's self-reported flows on a monthly basis (Interview #29, Brasilia). For years, ANA had relied on SABESP's monitoring stations and reporting.[17] During the seven months that I interviewed and attended meetings (August 2013-April 2014), several grave concerns over access to information would surface. As the drought worsened and the reservoirs emptied in the months that followed, it became increasingly apparent to everyone that none of the existing agencies had authority to regulate SABESP.

When the drought became local and international news, and as district judges were pressuring state authorities to declare a state of emergency, São Paulo's situation needed to appear under control. São Paulo Governor Geraldo Alckmin, who was up for reelection for a fifth term, continued to promise that the city of São Paulo would not run out of water, assuring people that third and fourth reserves would be tapped from the dead storage (explaned in detail in section 3.4.2) to supply water in the event of a real emergency situation [*G1 Globo*, 2014; *Maciel and Fernandes*, 2015]. The National Water Agency affirmed in the Legislative Assembly capturing this volume was not possible. Meanwhile, Alckmin used the imminent crisis argument to strong-arm federal authorities to allow a long-disputed water transfer from Paraiba do Sul, which enraged the neighboring Rio de Janeiro Governor.

Residents in the state and city of São Paulo did not experience the drought equally. There were neighborhoods in the MRSP where people saw their water cut off for 10 to 24 hours at a time, while some of the wealthy neighborhoods experienced almost no cuts

[17] In early 2014, under growing pressure from PCJ river basin committee members and the *Ministério Público*, ANA installed three new monitoring station upstream of the Cantareira's reservoirs.

during the entire crisis. The explanation provided by SABESP was that the pressure reduction, used to reduce consumption and water loss, also affected water deliveries to high points and end-of-the-line regions in the periphery of the city. These, as it happens, were often poorer neighborhoods where households did not have water tanks to store reserves during water cut offs.

3.4.2 The drought and muddying of information

In general, the onset of the water crisis was obscured, rather than clarified, by technical information. Authorities often used technical jargon to mask or deliberately mischaracterize the severity of the problem. Three clear examples are provided in the subsections that follow. The first alarming signs came early in October 2013 when Cantareira reservoir levels were at an unusually low 37%. The rainy season in the Southeast region begins in October and ends in March. By January 2014, three months into the wet season, some CBH members raised concerns over unusually low rainfall for the season. Instead of filling up, the reservoir system was emptying fast, at an estimated 60 thousand liters per month. In February 2014, the GTAG (Technical Advisory Management Group) was belatedly formed to manage the crisis. It was comprised of one representative from each of the agencies ANA, DAEE, and SABESP, plus the Executive secretaries for the PCJ and Alto Tietê river basin committees (though both committee secretaries at the time were DAEE state employees and occupy seats as representatives of the public sector within the committees).

3.4.2.1 Reservoir levels and percentages

In October 2013, uncertainty began to set in among basin committee members over basic information about the system. Take, for example, the unnecessary confusion over reservoir levels and the use of dead storage. SABESP had always reported reservoir levels in percentages rather than total volume. This would not be an issue if the method for calculating percentages were clear; however, what constituted 100% of the volume changed over the drought period. Twice in 2014, once on May 16 and again on October 20, the reservoir volume percentage reported online jumped overnight from single to double digits. Further confusion came from the unconventional calculations used to report percentages: instead of adding the newly available (dead) volume to the numerator and denominator to calculate the percentage based on the new total volume, SABESP calculations left the denominator unchanged. Mathematical conventions aside, there were two other issues with this reporting. First, it masked the severity of the drought by artificially inflating the reservoir levels (by dividing by a smaller number), and second, it complicated any attempted comparisons between the current situation and that of previous months or years. Is 15% today the same as 15% last month or last year, or in relation to the last drought? Confusion ensued over which percentage to use when speaking about the state of the Cantareira. As the crisis evolved, SABESP changed its website to report reservoir levels in three different percentages. Only in March 2015 did the courts finally require SABESP to clarify its reporting methods and reveal the real volumes behind the calculated percentages. The SABESP website continues to report three percentages. CBH members would continue to raise similar questions over numerous other sources of information.

In December 2013, the PCJ Consortium was the first to announce a gloomy outlook for the Cantareira and to question current consumption rates [*Consórcio PCJ*, 2014]. The central question at monthly meetings of the technical subcommittee for Hydrological Monitoring (CT-MH) was whether the Cantareira could continue to produce deliveries totaling 36 m^3/s (i.e., 33 m^3/s to MRSP and 3 m^3/s to PCJ). The repeated answer from the subcommittee's coordinator was that in times of need, the Water Banks allowed each basin to utilize its water "savings." However, based on sources outside SABESP, the leading consultant to the PCJ Consortium had announced in a closed-door meeting in September 2013 that, given the absence of physical space to store water in the Water Banks, the water "savings" existed only on paper [meeting attendance #2, September 2013].

In January 2014, when tensions were running high and news media showed up to report on that month's CT-MH meeting, a young state prosecutor from the *Ministério Público* representing that institution's environmental group GAEMA decided to confront the subcommittee's coordinator, Aster Dias de Andrade, in front of the cameras. After reading articles of the water law and leading the coordinator through a series of questions that he seemed increasingly uncomfortable answering, Dr. Alexandra Facciolli asked her final question: Today SABESP has as much water in savings as the water stored in the entire Cantareira system. How is this possible? It is because the water banks are virtual, right, they are not real? After a long pause and a faint sign of agreement from Mr. Dias, Dr. Facciolli made a motion to suspend the use of the water banks until better information about the state of the reservoirs could be collected [meeting attendance #3, January

2014]. In the end, the water banks, which were created for safety during times of emergency, had helped to expedite the drawdown of the Cantareira system.

3.4.2.2 Dead storage or "dead volume"

Levels in the Cantareira reservoir and the use of water banks are directly related to another management instrument that became controversial: the use of dead storage ("*Volumen Morto*"). Dead storage is the textbook technical term that refers to the water stored in a reservoir underneath the gravity-fed outlet (Figure 3.4). This water is not normally intended for use [*Votruba and Broža*, 1989]. Despite the consistent use of the term "dead storage" in all official documents for the Cantareira system, state authorities chose to refer to this additional volume as "technical reserve" or "strategic reserves" during this drought event [*G1 Globo*, 2015]. The pumping of dead storage on its own is not controversial, but how the use of the dead storage was handled turned it into another tangle of information that added to growing distrust. First, the actual volume of water that was available in dead storage was ambiguous, and three water institutions with authority on the matter (GTAG, ANA, SABESP) reported three different values [*Martins*, 2014]. Second, the dead storage was not originally intended for use, and could only be allocated via a formal process. The authorization according to ANA and DAEE was allegedly done in two stages.

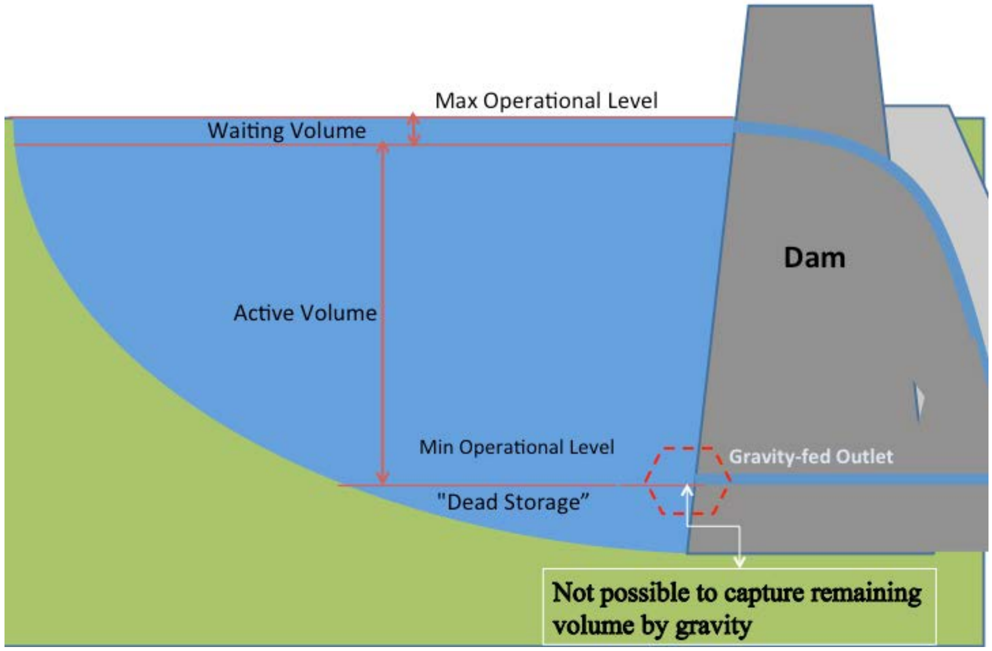

Figure 3.4 Dead storage [Source: adapted from original graphic by A.C. Zuffo]

SABESP reported on their website to have requested an emergency permit from ANA and DAEE to access a portion of the dead storage on two different occasions – first on April 17, and again on September 17, 2014. ANA's timeline places the request in October, while the official Resolution was only issued on November 17.[18] However, official documents presented by SABESP on April 17 showed construction and investment to pump from dead storage volumes 1 and 2 scheduled to begin in mid-May and October of 2014 [*SABESP*, 2014b]. It is unclear whether SABESP made an authorization request or an announcement, and only those members of GTAG present at the April 17 meeting know how the plans were presented that day. What is clear is that the custom-made floating pumps and public works, which cost R$80 million (USD $37

[18] ANA/DAEE 1672 (2014). *Resolução Conjunta* ANA/DAEE Nº 1672, de 17 de Novembro de 2014.

million at the time), were commissioned months ahead of the installation. Prior to authorizing access to dead storage for a second time in October 2014, ANA requested a more detailed plan on the risks of emptying the system. This analysis, based on simulation of past rainfall variability, was to be delivered at the end of September. However, SABESP requested a deadline extension three times. GAEMA also tried to stop the use of dead storage through a civil action suit. Neither of these attempts succeeded.

The failure of both these efforts to make SABESP's actions more transparent was noteworthy. Both ANA (the federal licensing agency) and MP-GAEMA (the state-level public prosecutor for environmental affairs) had legal authority to require SABESP to provide more details of its operational plans for the Cantareira system. By failing to respond, SABESP made a bold statement that it could disregard the authority of the licensing, monitoring, and regulatory institutions that oversaw the utility company.

To add to the offense, ANA made an independent visit to the Atibainha reservoir on October 14 (where water would be newly withdrawn from dead storage), and found the reservoir already below authorized levels, even though SABESP reporting did not admit this fact [*Korman*, 2014; *Monteiro and Rodrigues*, 2014]. When ANA went back the next day on October 15, for a second visit, the technician found that the water gauge had been removed, and the online monitoring system was offline for 2 days afterwards. ANA eventually left the GTAG in August 2014 over differences with SSRH Secretary, Mauro Acre, on the "proposed limitations for water withdrawal from the Cantareira system and in the absence of following recommended flow rates to the MRSP to be applied since June 30, 2014” [*ANA*, 2014].

3.4.2.3 Pressure Reduction Valves (PRV)

The use of pressure reduction valves (PRVs) to reduce physical water loss in the distribution system also posed some contradictions. A diagram on the SABESP website purported to show how flow in the distribution system is monitored and can be reduced remotely. The website also made a point of differentiating between pressure reduction, which leaves some water pressure in the pipes, and *rodizio* (rotation based on turning off the flow, *fecha registro*), which leaves pipes depressurized. The website displayed, for example, the need to have high pressure during the mornings, while pressure could be reduced at night and in the early morning. To quote from the website: “Each sector has a remote measurement system to identify the amount of water consumed and the flow in the pipes during each hour of the day. Based on this information, the amount of water given the time of day can be controlled through linked network valves” [SABESP, n.d.].

In early 2015, newspapers reported interviews with SABESP employees and residents of affected neighborhoods, some live, which told a different story than the one SABESP was presenting on their site. News reports asserted that 50% of the water demand reduction came from people’s water being turned off altogether [*Leite*, 2015, 2016]. A high-level official, not named in the report, was quoted as saying, "We have 60% of the network in the metropolitan area controlled by PRVs. This leaves 40% of the network. In these areas, we need to revert to [closing] operations in the street. There's no way. A part of the city ends up being shut off." It is unclear whether PRVs forced the stated 50% demand reduction or just aided in achieving it. To put this in context, in the US, restrictions can be voluntarily (e.g., no pool and outdoor water use on certain days) or mandatory (e.g., California 20% required reduction), but even the most severe mandatory reductions require collaboration from the public, and people are informed in advance. Prior to 2015, SABESP did not inform consumers in regions affected by PRVs. Only in early 2015 could customers log on to SABESP's website to learn if their neighborhood would be affected by pressure reductions. Consequently, PRVs had the effect of reducing consumption and water loss, a fact SABESP openly admits. The utility did not declare mandatory restrictions. Yet, hidden in technical jargon of PRVs, is the undeclared *rodizio* that achieved the same effect.

3.4.3 Lack of authority

The basin committees in São Paulo are among the oldest in the country. They have decades of experience and have provided a platform for negotiations and management discussions with the participation of civil society on issues of water quantity and quality. The CBH and technical councils had created arenas to resolve critical problems; however, when the crisis began, frustration and concerns grew as key stakeholders and committee members were excluded from conversations. It became apparent that the most difficult decisions were being made elsewhere. The state Governor centralized the discussion and deliberations around a handful of technical actors, leaving the CBH out of the conversation.

The day before Carnival holiday in 2014, during a February monitoring subcommittee meeting, state prosecutor Facciolli expressed her frustration over the lack of information on water availability that rendered the role of the CT-MH inconsequential. The morning meeting had started late, as heavy rainfall had delayed the arrivals of many council members. When the meeting finally began, the information presented did not include February flows because the data had not yet been released to coordinators (and arguably to ANA). Facciolli took the microphone and questioned the legitimacy of any decision from a council lacking the most basic and up-to-date information on the status of the Cantateira reservoirs. Seven months later, GAEMA of the *Ministério Público* filed a civil action suit against ANA/DAEE/SABESP for inadmissible risk in the operations of the system, for negligence in their responsibilities as regulating and management agencies, and for the economic, social, and environmental risks imposed on the region [*GAEMA-MP*, 2014]. The civil suit further underscored the lack of authority of these agencies in their role as regulators.

As illustrated in several previous examples of the deliberate muddying of information, there were institutions that were actively trying to be involved. Some entities questioned and pressed the state and federal agencies to do their job – in GAEMA's case, for example, taking the cases to the courts. The inaction of the regulatory agencies like ANA, ARSEPS, and DAEE showed that they lacked the both authority to enforce the decisions that were their legal responsibility and the flexibility to interpret the law. Instead, powerful players found other means to resolve their problem outside of the established channels. GTAG is an example of this circumvention. Given the emergency situation, laws and regulations were rushed, bent, and at times bypassed all together (e.g., GTAG resolutions or emergency construction of public works), effectively weakening the power and relevance of the existing institutions. As we see next, even SABESP, the party that most benefitted from ANA and DAEE's collective impotence, had its hands tied.

The complex power dynamics were most obvious only after the gubernatorial election, when tapes recording discussions among high-level administrators surfaced. A leaked tape of SABESP officials discussing their frustration over their minimal role and inability to prevent the crisis came to light after the November 2014 elections. Paulo Massato, Metropolitan Director of SABESP, called for São Paulo's exodus for vacation, stating that "there will be no water to take showers, to clean the house." SABESP's president at the time, Dilma Pena, was caught on the same tape saying that she wished SABESP had begun water conservation campaigns earlier, and lamenting that "superior orders" had prevented SABESP from being more open and involved with the public.[19] The Governor refused to declare a state of emergency. Instead he explained that federal authorities induced the water shortages, hence, forcing the city into a state of emergency [*do Valle*, 2015]: "When the ANA determines that you have to reduce from 33 to 17 [cubic meters per second] in the Cantareira, it is obvious that you are already under restriction … There is no need to decree [a state of emergency], this is more than explicit." Thus, he attributed the water shortages to ANA's request to reduce

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[19] The tape of the two administrators talking can be heard here: http://www1.folha.uol.com.br/cotidiano/2014/10/1537493-orientacao-superior-impediu-alerta-sobre-crise-diz-presidente-da-sabesp.shtml (Accessed 12-15-2015)

withdrawals from the Cantareira system rather than acknowledging the need for preventative measures. In fact, no official statement of emergency was ever announced by the Governor. It was eventually reported in August 2014 that authorities at SABESP knew the severity of the situation in detail, since several rationing schemes had been presented in a plan entitled *Rodízio do Sistema Cantareira 2014* dated January 2014 [*SABESP*, 2014d]. However, on October 15, 2014 SABESP's president revealed in a deposition that the company was prohibited by the Tribunal Judge from mentioning "drought" or "restrictions/rationing" in any of their public campaigns prior to the elections [*Boghossian and Gama*, 2014; *Korman*, 2014].

Several red flags heralding an acute water crisis would be raised months prior to the crisis as shown in timeline of events superimposed on reservoir levels (Figure 3.5). Throughout the drought, the lack of authority over water in São Paulo became increasingly apparent. ANA made repeated attempts to impose criteria and limits for water deliveries to the Cantareira. They were not successful. Joint resolutions from ANA and DAEE justified allocation requests based on the SABESP's technical analysis rather than their own. Within the institutional structure of the state, DAEE and SABESP are two arms of the state government overseen by the SSRH. A number of experts interviewed expressed their skepticism of DAEE's authority over SABESP, since the latter is a more technically equipped and financially powerful institution (Interview #12, 14, 20). Indeed, SABESP's private and public arms made it susceptible to conflicts between economic, political and social interests.

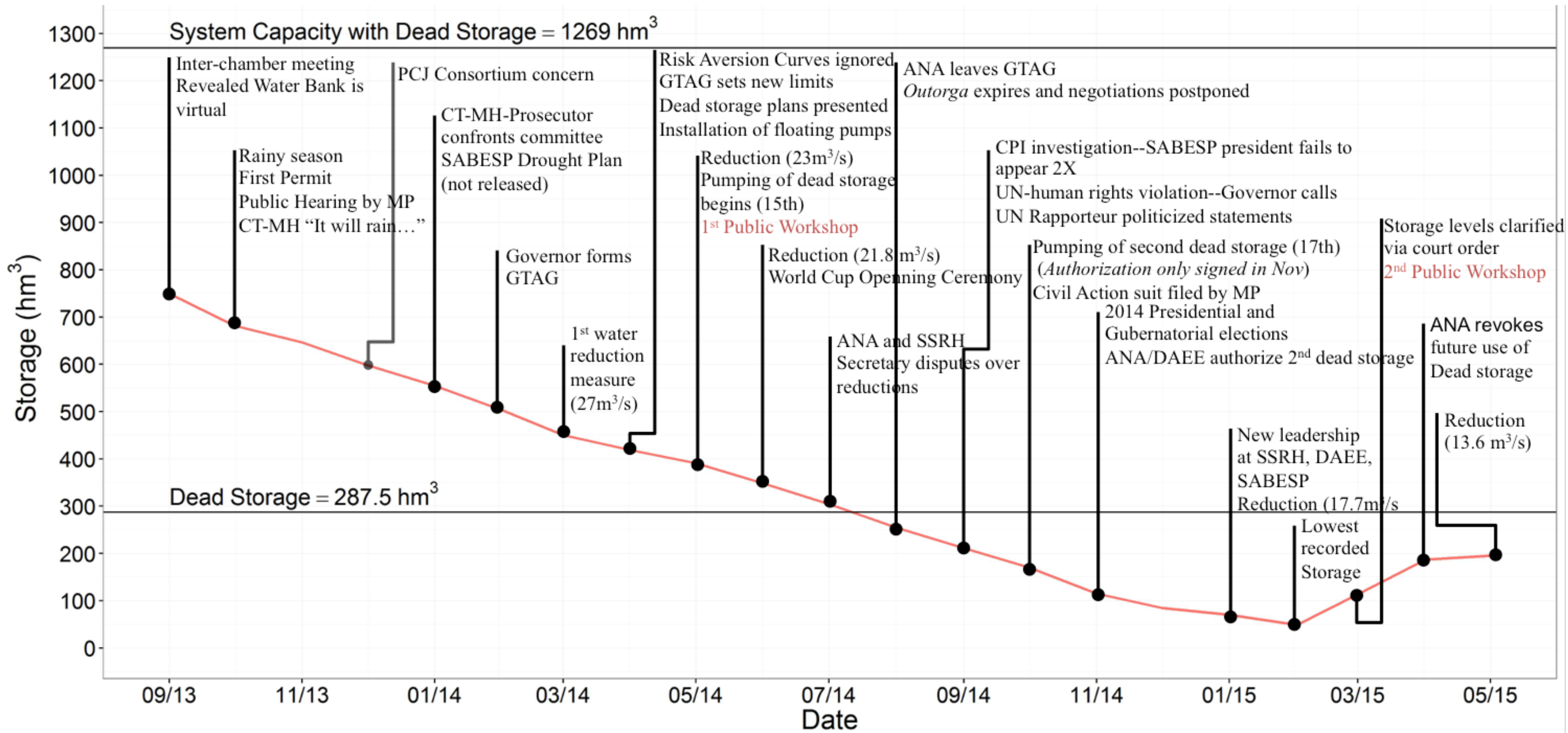

Figure 3.5 Timeline of events and reservoir levels during the 2013-2015 drought

3.4.4 Water issues and political power in federal and state politics

Although national and governmental politics are beyond the scope of this chapter, it is worth mentioning a few notable examples of the role of political power in São Paulo's water crisis. These events show the ways in which technical information was used to influence public perception, and they reveal how several layers of politics played into the dissemination of information and complicated actions in the midst of a devastating natural event. The drought crisis continued to worsen during the run-up to the 2014 presidential and gubernatorial election. In a few words, the water crisis entered into the political strategies of competing parties and office-holders at various levels of government. Whoever could create a perception of competence – or, conversely, make a charge of incompetence stick – won electoral approval points.

The 2014 presidential and state gubernatorial elections added political salience to the water conflict as candidates used the issue to attack the opposition at the federal and state levels. During the gubernatorial debates, several candidates attacked incumbent São Paulo Governor Alckmin (PSDB candidate), citing his failure to act quickly and transparently, but to no avail. Alckmin won the elections in the first round with more than 60% of the popular vote. During a debate among presidential candidates on October 20, 2014, incumbent president Dilma Rousseff (PT candidate) used the water crisis for the first time as an example of how her opponent's party had lacked any foresight to plan for an event as critical as the one experienced in São Paulo.

At the start of 2016, there was much speculation that four-time governor Alckmin would seek PSDB's nomination for the 2018 presidential election. Governor Alckmin received the Lúcio Costa Award from the Urban Development Commission for the "excellence" with which he had handled the drought. One of Alckmin's party colleagues in the House of Representatives made the award nomination. The prize was awarded on October 23, 2015, when the reservoirs were at -13.5%. Alckmin expressed to the media, "All modesty aside, the award is well deserved." Partisan politics also played an important role. Questioning the Governor's decisions about water could be interpreted as being in alliance with the opposition party (Worker's Party, or PT). This was undesirable in the divisive political climate leading up to the Brazilian presidential impeachment. PSDB would later play an important role in the protest and political coalition to impeach Rousseff (PT) from the presidency. Given the troubled state of current politics in Brazil, the PSDB (Alckimin's party) needed to gather all the momentum it could for the next presidential election.

The level of denial by authorities and the lack of information (exposed only during the drought) thwarted any participatory efforts that came from outside the Governor's circle. In fact, despite existing drought plans, acknowledgement from top-level administrators at SABESP that situation was critical, and attempts by regulators and other authorities to intervene, drought mitigation actions were delayed. These events make sense only when juxtaposed with the political climate created by the November 2014 presidential and governmental elections, and with the motions to impeach President Rousseff, which began in May 2016. Power and politics were central to hindering governance.

3.5 Shared Vision Model and Shared Vision Planning interventions

Given the perceived information asymmetries and importance of access to technical information, I initiated an academic collaboration with Palmer and Werick. As noted before, both were experts in collaborative modeling and drought management. My direct collaboration with Faculty at UNICAMP (located in the PCJ basin) and contact with active members of the PCJ river basin councils over the course of more than six months motivated me to take part in organizing two public workshops (in May 2014 and March 2015) to help demonstrate what an open and transparent dialogue would look like if applied in São Paulo's water conflicts. This section describes the experimental workshops and what we learned, given the failure to build collaboration among all parties in an attempt to resolve the immediate water conflict. This section is organized as follows. Section 3.5.1 describes the Shared Vision Model developed for the workshops. Section 3.5.2 and 3.5.3 use the two-stage framework—five dimensions of participation and mechanisms for building credibility, salience, and legitimacy—developed in Chapter 2 to describe and report on the design of these workshop agenda and accomplishment. Section 3.5.4 explains the challenges to collaboration and limitation of the SVP effort.

3.5.1 The Shared Vision Model (SVM)

The SVM is a simulation model of the Cantareira system's inflows and outflows based on 83 years of data. It was constructed by William Werick[20] in Microsoft Excel to

[20] Werick developed the SVM for the workshops and later worked closely with Falconi and Palmer to ensure that all members of the team could run or change the model as needed to test future policy options.

maximize its availability to the public during and after the two workshops. Visual simulations are favored as ideal for stakeholder engagement processes [*Winz et al.*, 2009], so the SVM allows easy graphics and visual adjustment of simulation parameters to create several "if-then" scenarios. This feature allows users to test policy alternatives systematically in real-time. Given the drought crisis in São Paulo, prompt availability of model results was important. Based on changes in demand, the model provides visual outputs of current reservoir storage in the Cantareira system (shown in blue in cubic hectometers in Figure 3.6), monthly water deficit (shown in red in m^3/s), and yearly Position Analysis (not shown). The model was validated using historical data. Although the SVM was built as a tool for discussions and as an attempt to facilitate stakeholder engagement, we consider it a "mock" model given the limited feedback it received and the lack of full validation by all key stakeholders.

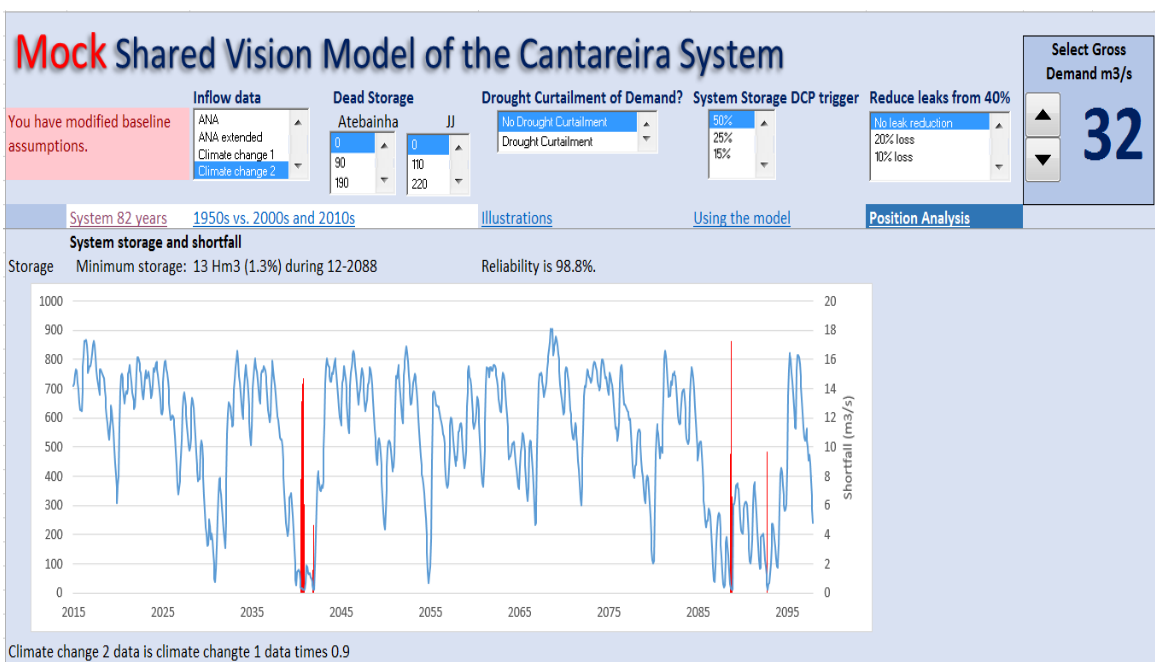

Figure 3.6 The SVM interface

3.5.2 Stage one: defining the five dimensions of participation for São Paulo

The following subsections describe the workshop events using the framework presented in detail in previous chapter, Section 2.4 and 2.5. Table 3.1 summarizes stage one of the SVP participatory process.

Table 3.1 Stage 1 – Five dimension of participation

Dimension 1: Stakeholders *1a. Core Participants:* The workshops were intended to include all major actors in the Cantareira water dispute. The event was open to the public and announced via newspapers and on UNICAMP's website, as well as via the Brazilian Water Resources Association list server. Formal invitations from UNICAMP administration were sent to ANA, DAEE, SSRH, MP GAEMA, USP professors, and the Executive secretaries of the PCJ and Alto Tietê River Basin Committees. Those present at each workshop are detailed below. *1b. Organizing team:* Falconi, Palmer, and Werick with the institutional support of UNICAMP
Dimension 2. Stage of involvement: Involved in problem definition, model use, and scenario testing. Model use was limited to two sessions during the two workshops where alternative scenario testing was possible. Feedback on how the model could be useful for a drought event such as the one São Paulo was experiencing was taken into consideration in the second version of the model but not to the extent necessary for a true participatory model.
Dimension 3. Degree of Involvement: At first, the degree of involvement was set low at Involved/Collaborative, but could expand to Empowerment in the event the efforts gained traction (please refer to Table 2.1 for the definitions of different degrees of involvement). We had intended the workshops to create a collaborative environment and a more involved engagement of participants in drought management, but as outsiders we had no control over the general drought management process in São Paulo. We enlisted and engaged key stakeholders from the PCJ basin committees and academics working directly to advise the PCJ Consortium and committees, but not all actors saw the benefit of participating. As a result, the effort remained an "involved" effort (see Table 2.1), but the combination of political timing and the drought conflict made sustained collaboration among involved parties difficult. For example, Rui Brasil, a high-level representative from the SSRH was present in the second workshop; however, he limited his participation to a generic presentation and a brief session of questions and answers before departing.

Dimension 4. Level of influence: The workshops had no influence in the operations and management of the system. At a very small scale, they influenced the ongoing actions of the *Ministério Público* and provided expert testimony and evidence for public hearings led by GAEMA on the impacts of the drought. (The reasons for low level of influence of the model and workshops are described in Section 3.5.3 and 3.5.4).
Dimension 5. Purpose: To illustrate what a participatory model would look like for the Cantareira system, and to demonstrate the expediency of a Shared Vision Model for evaluating relevant strategies during São Paulo's water negotiations and later the drought policy options.

3.5.2.1 Workshop 1: Shared Vision Planning for the Cantareira system

The *International Workshop on Conflict Resolution and Water Scarcity in São Paulo* took place on May 15, 2014, on the very day the emergency floating pumps were activated to access the first dead storage. The main goal of the first workshop was to illustrate what a participatory computer model would look like for the Cantareira system, and to assess the possibility of a participatory platform for the re-negotiation of water allocations. As the Cantareira fell to its lowest recorded level (as of that date), SABESP requested a special permit signed by the regulating agencies, ANA and DAEE, to authorize the use of the dead storage. There was concern from the population at large, but also a growing uncertainty among the PCJ basin committee's technical and non-technical members alike, apparent from the number of unanswered questions they had raised.

The mock SVM is visual and has a simple interface that provides easy access to questions that were often raised during discussions, such as: How much water is left in the reservoirs? Can an estimate of days of water supply left be made based on current demand levels? What would happen if demand was reduced? What is the degree of certainty for the estimated values? The SVM is intended for use in real time to explore several scenarios based on current system storage levels and to demonstrate the model's various useful features in water allocation discussions for the Cantareira system. The model generated considerable interest, but attendees raised concerns over the viability of a SVP platform given the critical situation at the time.

The afternoon session was dedicated to subdivided group discussions and a feasibility discussion at large. The attendees – who numbered over 150 and included government agency employees, water utility managers, academics, and representatives of private entities – were asked five triage questions (described in Section 4.3.4.1) designed to evaluate whether SVP could be successful [*Werick and Palmer*, 2004]. The assembled participants overwhelmingly agreed on the value of attempting a more participatory water allocation process. Yet they also noted, nearly unanimously, that a small number of well-positioned stakeholders who were not officially present at the workshop (like SABESP and the state authorities) would not welcome the increased scrutiny of stakeholder participation.

The meeting did not bring about change in any management operations of the Cantareira system. It did, however, influence how people thought about technical information. The most tangible evidence of this is the *Ministério Público*'s decision to request via the Public Information Act that SABESP provide several years of data from the monitoring stations upstream and downstream of the reservoirs. The request was drafted by the MP's technical analysts and revised by several of the presenters at the Workshop including our research team. The *Ministério Público* cited our workshop specifically as the motivation for their request. This was the first of several requests that *Ministério Público* would make of SABESP.

3.5.2.2 Workshop 2: Shared Vision Model and virtual droughts

The *Forum on Water Sustainability* took place over two days, March 17 and 18, 2015. It was held almost one year into the drought, ten months after the first workshop. Ambiguity over the real socioeconomic consequences of the drought made for a very tense start to 2015. The Cantareira system had set a new all-time record low storage in January 2015 and was delivering a mere 14.2 m^3/s in March 2015, less than half of the normal water supply. The forum had over 300 registered attendees, as well as some 500 remote, online live viewers.

The goal of the second workshop was to create drought preparedness options based on virtual drought policy alternatives so that participants could explore the potential trade-offs and consequences in the controlled simulation environment of the virtual models. Leading the workshop organization were UNICAMP's Office of International Affairs and the Rector's strategic thinking group PENSES, which drew high-level authorities as speakers and participants. Most notably in attendance from government agencies were: Vicente Andreu Guillo, President of ANA; Rui Brasil Assis, Coordinator at the state SSRH; and Dr. Alexandra Faccioli Martin and Dr. Sandra Akemi Kishi, justice prosecutors from the state and federal levels of the *Ministerio Publico*, respectively. Water resources coordinator Prof. Jose Tundisi, of the Brazilian Academy of Science, was a notable attendee from the non-state sector. Also present was Prof. Margaret Keck, from the Political Science department at the Johns Hopkins University, and an expert in Brazilian water institutions and water reform. The event drew some government representatives, but SABESP and DAEE were notably missing, and the SSRH representative limited his participation to a generic presentation and a brief session of questions and answers before departing. Their absence undermined any potential influence a participatory effort could have, since the legitimacy of the model depends on validation and usefulness for real decisions.

Given the new leadership in the state water agencies, there was some optimism, but the severity of the situation was growing. We viewed the second workshop as a second chance to assess the possibility of SVP in São Paulo. The SVM presentations featured a second version of the model with new drought recovery functions for the Cantareira system to evaluate potential strategic actions based on drought indicators and triggers. The focus of the model presentation was to highlight the usefulness of virtual drought exercises. The model was updated to include more critical scenarios experienced in 2014-2015 and to assess trade-offs based on recovery drought plans given optimistic and pessimistic future rainfall scenarios. Palmer presented other drought examples, such as California's response to the 2012-2015 drought, to showcase how drought monitoring and established drought indicators, triggers points, and responses had mitigated the impacts for those specific situations. The second workshop was successful in providing an assessment of the ongoing drought but, like the first workshop, it was not successful in generating the core changes necessary to make the process more inclusive of other stakeholders.

Question and answer sessions and small group discussions at the workshops showed that attendees could imagine a better outcome from a transparent process. However, attendees also recognized that there were several issues at play that could undermine the process, including growing demonstrations against president Rousseff. It was simply not in the best interest of all parties involved to have a more collaborative decision-making platform such as the one offered by SVP. The notable absence of state authorities had the result of limiting a collaborative action and shielding their decisions from an open public debate. As others have recognized, lack of engagement is not uncommon, and "it is unclear how nonparticipation can be dealt with beyond repeated and sensitive invitations, given that participation [is] voluntary and any pressure would [be] counterproductive" [*Chan et al.*, 2010, p.10].

3.5.3 Stage Two: designing a model and intervention to help building credibility, salience, and legitimacy

This section applies the concept of boundary objects (described in Section 2.5.1) to explain how the computer SVM and workshops were designed to function. Model effectiveness is described by three criteria: 1) credibility—accurate and reliable model inputs that build an accurate system description (from participants' point of view), 2) salience —flexibility and relevance to stakeholder's needs over time, and 3) legitimacy—participants' trust in the neutrality of model information in spite of opposing interests.

Credibility—Providing accurate information in an open forum of diverse stakeholders was a central motivation for the proposed SVP. Although we were not part of all the relevant dialogues, it was possible to identify the knowledge gaps and discrepancies in information available among parties. The inputs for the SVM came from official data provided by ANA during the permit negotiations process, and validation data was acquired from SABESP's website. The Excel modeling platform was accessible and could be downloaded from our website and adapted by anyone, since the database was included. We do not know if parties not present at the workshops found the system representation to be accurate from their point of view. The model was acceptable to those present, but they did not get to interact with it beyond the workshops.

Salience—The issues and relevant variables to include in the model came from the six-months between August 2013 and February 2014 that I spent doing fieldwork. This included attending over two dozen meetings and conducting 33 interviews with primarily *técnicos* (see Methodological notes in Appendix B). As we built the model, we relied on key collaborators and interviews to ground the information and identify crucial gaps. However, in a real participatory model, stakeholders need to provide direct feedback to increase the relevance to the issues they care about. The SVM did not become a channel for frequent communication. There were no follow-on efforts after the workshops to encourage participation, given the failure to gain traction from main decision makers.

The model failed to gain greater saliency, and the research team did not deem it appropriate to continue to engage stakeholders when their time and efforts were not going to change decisions.

Legitimacy—The direct outputs of the model were never used for making decisions. We are aware that a small group of stakeholders used the information and momentum created at the workshops in other platforms. These uses included two legal actions, testimony, and additional model development as follows:

- the university made a formal request to water authorities to create an open database of the Cantareira system;
- GAEMA filed a request for hydrological data on the Cantareira system via the Freedom of Information Act;
- Palmer (supported by Falconi) provided expert testimony at a public hearing for state and federal prosecutors; and
- GAEMA's technical advisor developed modeling capability for internal use.

These four uses all fell outside of the participatory effort and were not the direct, intended purpose of the SVM. The intention of bringing participatory modeling to the workshops was to use models as tools to reason through complexity.

This research argues that participatory models are valuable to governance for several reasons. First, participatory modeling identifies information gaps and reduces information asymmetries. Second, the incremental and iterative nature of building a model helps build trust, which fosters cooperation and facilitates the strengthening of networks. Third, participatory efforts give stakeholders a voice in the agenda and in what will be included for analysis, which is important because modeling is by necessity a simplification of reality. In non-participatory settings, decisions about problem and model formulation fall to the modelers themselves. Finally, participatory models provide stakeholders a platform for coming to terms with the real tradeoffs necessary to reach negotiated decisions, even when these are contentious. Our workshop interventions, however, did not produce all of these benefits. We explore some of the reasons they fell short in the next section.

3.5.4 Challenges to collaboration and limitations of the SVP effort

The São Paulo case study illustrates that participation is an arduous process, hard to define, harder still to operationalize, and requiring far more than a 'seat at the table.' Past efforts by CBHs in São Paulo and elsewhere in Brazil to mobilize people and resources provide examples of successful participation that built political power [*Abers and Keck*, 2007]. The CBH-PCJ and CBH-Alto Tietê created a platform for debate even prior to the 1991 reform. The PCJ basin in particular leveraged political support to make institutional arrangements real. Practical actions and concrete practices that forced people to work together were one such political construction of power. By working collaboratively in small projects, the CBHs demonstrated their capacity to build and strengthen their network, and by extension, to nurture trust [*Abers and Keck*, 2007]. This makes the failure to garner collaboration all the more disappointing.

The efforts over a year and a half to engage SABESP and state water authorities failed as the drought worsened. During that time period, SABESP cut water deliveries to the MRSP to as little as 14 m^3/s on February of 2015 under an undisclosed drought plan.

From the workshops and the failed participatory efforts, I conclude that there were non-water issues (such as the state and partisan politics), that sidelined the water conflict, and that state authorities had pursued alternative ways to resolve the water management situation. Most alternative resolutions left out the regulating bodies that were established by federal and state laws, and all sidelined the platforms created by the CBHs. These "non-water" issues and their relations to access to water information were difficult to untangle at the time of the workshops, both for our research team and for all those involved. With hindsight, it is possible to deduce what prevented a collaborative solution.

It became clear in the workshops that it was not in the best interest of SABESP (and, indirectly, the São Paulo state authorities) to partake in an open and transparent process like SVP. There must be clear gains to each of the parties if collaborative efforts and decisions are to succeed. In this case, not every stakeholder stood to benefit equally from engagement and cooperation; some found it advantageous to remain inactive. Those with more power to make decisions did not want other parties to have open and transparent access to information because it would weaken their positions, open the door to scrutiny, and legitimize platforms – such as those created by our workshop interventions, among similar efforts – where people could openly question their motivations.

Indeed, what participation means in a place as large and complex as São Paulo is not self-evident. There are some successful examples of collaborations like the PCJ consortium that formed a coalition of companies, municipal governments, and engineers to garner support for solving longstanding pollution problems in the Piracicaba river, and the CBH that created formal representation of various pre-defined sectors in a formal deliberative body. Notably, farmers were absent from this procses. This progress in participation was long and ardeous process that should not be taken as insignificant. Nevertheless, several lines of evidence allow us to infer that the extent of participation and the authority of São Paulo's water institutions were much more limited than the reputation had it prior to the drought. First, access to information was unequal. Unequal information can significantly undermine the bargaining power of different parties to negotiate water allocations. Information asymmetries include delays or omission of important information, and can provide advantages in negotiations that benefit some parties over others [*Pfaff et al.*, 2013]. Second, SABESP and state authorities were able to derail the system, as seen in a previous analysis of how powerful players can circumvent the rules and seek other platforms to resolve their problems [*Abers and Keck*, 2006]. The timing of the drought (in terms of socio-political climate) only made this more obvious. The CBHs' inability to change policy outcomes further legitimized decisions that were being made elsewhere; indeed, it appeared as if the CBH agreed with those decisions, when in fact they had raised several concerns. Third, despite the CBHs' prior track records mobilizing resources, the CBH platform failed to bring different actors and sectors during the São Paulo drought to build on existing institutions and collaborative experience. Unable to strengthen their cause by building on collaborations, several water institutions saw their role and authority eroded. In the case of ANA, for example, its regulatory role was minimized after it had no other choice than to leave GTAG. In short, while some forms of participation did take place in São Paulo's river basins, it is also true that key institutions and actors carried very little authority to shape the agenda. The larger and more pressing nature of the drought crisis merely served to make the limited extent of participation more apparent.

In light of state and national elections, the World Cup, and many other political battles underway, it appears that SABESP felt that shielding their decisions from public scrutiny lowered the risk that they would look incompetent in tackling the crisis. After all, SABESP and state regulatory bodies answer to the governor of São Paulo, who also appoints their high-level administrators.[21] Water authorities might also have believed that the situation was too urgent and necessitated rapid technical decision that need not be debated in an open forum. This would be consistent with Brazilian *técnicos'* perspectives on the technocratic and insulated manner that decisions have been made in the past. It does *técnicos* of this generation. This however, does not explain why ANA and other agencies were excluded from taking part in these decisions. Given the political climate, transparency as to how technical decisions were actually being made would have intensified the public's negative perceptions of SABESP and of the Governor, at least in the short run. In the long run, however, lack of transparency might hurt public opinion of these institutions and undermine their authority to carry out their duties. The immediate political crisis meant that short-term consequences were the primary consideration for the government ignoring any long-term consequences it may have on institutional governance.

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[21] Aside from the accountability to the Governor, SABESP also had private-sector restrictions, e.g., loan covenants, that limited its powers.

3.6 Conclusions

This chapter has focused on a case study of the São Paulo drought of 2013-15, with special emphasis on participation and on the complex institutional challenges that impede adaptive governance. Over the past 20 years, São Paulo has worked to implement ambitious state and national reforms, codifying and institutionalizing joint water management of the Cantareira system. However, the unprecedented drought revealed both the limitations of the current system and the institutional challenges that must yet be overcome if São Paulo is ever to realize the IWRM promise of participatory water governance. The gap between IWRM's theory and practice in São Paulo's case provides four important lessons:

1) Participation in the CBHs was limited even before the crisis, and a fact that became apparent as the drought worsened. As the situation escalated and deliberation actually started to matter, decisions were centralized rather than debated, effectively undermining several of the institutions that had experience solving problems and brokering solutions with diverse societal groups. In some cases, even an informative level of participation was lacking. The CBHs, and the public, heard of decisions only after the fact.

2) Publication of important, basic facts and technical information was delayed or omitted outright. This was the case not only on the matter of dead storage (or so-called "technical reserve"), but also for critical scenarios that were never discussed, contingency plans that went undisclosed for months, and water banks that turned out to exist only on paper. Other information was muddied – deliberately made confusing – to the point that the

courts had to mandate clarifications months later.

3) Unable to strengthen their cause by building on collaborations, several water institutions saw their role and authority eroded. Even SABESP, at times, lacked the autonomy to manage its own operations. Moreover, by shielding decisions from other players, authorities eroded whatever trust had been built among various water management institutions. This was apparent in the lack of consensus within the representatives of GTAG (ANA, DAEE, SSRH) and in the water permit negotiations that were subsequently postponed. The state not only weakened existing institutions, it also undermined the possibility of future cooperation and shared responsibility. The net result was a growing concern of the role and authority of different water institutions in general (not only during droughts).

4) Finally, water governance and adaptive capacity require an understanding that extends beyond technical know-how to the social and political challenges that institutions must face. Technical information and models can improve management decisions; they can also help build on small and concrete actions, but their adoption by and transfer in the policy arena are not automatic. The role of models in decision-making is embedded in social and political processes, and these in turn are subject to the institutions and people involved.

Efforts to frame IWRM as a purely technical discourse are misguided, given that participation and decentralization require the (re)distribution of power over water decisions. Adaptive capacity comes from institutions that have autonomy, problem-solving capabilities, and a certain level of authority and decision-making power that is earned only through experience. The IWRM framework argues for participation, which – if implemented as a change from the status quo – means that decision-making power will naturally shift to new arenas and new players. During the unprecedented drought, the state government could have enlisted existing institutions and basin committees to play an active role in solving the problem. It could have enabled them to act. But the state government chose to centralize decisions because it viewed participatory decision making as politically harmful (due to larger, non-water political conflicts) and unnecessary for managing the drought.

Questions of water quality and water quantity – like inflows and outflows or supply and demand – are technical matters that can be addressed by appropriate monitoring, measurements, and modeling. But questions of water allocation and water access – like how to institute water use restrictions and who bears the burden under circumstances of water scarcity – are political questions. The rain that began to fall in February 2015 eventually resolved the water crisis in São Paulo, but the lessons from this case study remain: a broader perspective on the underlying drivers of the technical and political challenges of water will be necessary to address future water crises.

CHAPTER 4. A SHARED VISION MODEL AND DROUGHT PREPAREDNESS: THE SÃO PAULO CASE STUDY[22]

4.1 Introduction

Providing safe, reliable, and inexpensive water to the world's megacities poses challenges that extend beyond engineering and hydrology. Water conflict resolution involves many competing demands and interests. Deliberation platforms are needed for comprehensive analysis and negotiation that incorporate stakeholders' concerns for

[22]This chapter is based on the academic collaborative effort initiated by Falconi in 2013 with Richard Palmer and William Werick for the purpose of developing and presenting a participatory model in São Paulo's case study. The post-workshop analysis starting in August 2014 also included the collaboration of master student, Grace Cambareri. This will be submitted to the *Journal of Environmental Science & Policy*, Falconi, S.M., Cambareri, G., Werick, W. and Palmer, R.N. (forthcoming). Falconi wrote initial and revised drafts of the paper and this chapter.

Contributions to the modelling workshops and post-workshop analysis of Section 4.5-4.6 are as follows:

Stefanie Falconi—all fieldwork in São Paulo was done 6 months ahead of time to determine what questions the model needed to address, document mining and gather data to build and validate model results; Falconi also mobilized local partners and solicited their participation at the two workshops. Falconi organized and presented the model at both workshops, and worked directly with Cambareri, Werick, Palmer on the parameters used to build the Shared Value Model (SVM) and Drought contingency plans. While the SVM was not participatory, the extensive fieldwork was intended to help improve the salience and credibility of the model.

Grace Cambareri updated and improved the SVM and developed R code to automate and streamline all aspects of SVM runs. Cambareri also developed and compared drought contingency plans based on several drought indicators, triggers, and action options.

William Werick formulated the SVM used at both workshop including reservoir and shortfall features, positions analysis, and virtual drought exercises. He led SVP exercises during both workshops, and recoded the SVM model post-workshops and worked with the team to validate the water balance, and include features such as position analysis, etc. for strategy analysis.

Richard Palmer oversaw the work by Falconi (pre- and post- workshop analysis) and Cambareri (SVM and DSR analysis). He led the SVP exercises at both workshops. Palmer also spent time in the field to work with local collaborators. He developed the concept of days of supplies remaining (DSR) and worked collaboratively with team to apply the concept to develop the Drought Planning contingency plan options.

public health and safety. Utility companies must bear public safety in mind and guard public good and wellbeing as they carry out system operations.

This chapter analyses the technical and supply challenges encountered by São Paulo in coping with one of the most significant droughts in the past 100 years. São Paulo's drought event displayed a combination of three major underlying drivers observed in the global water crisis: a gap between demand and supply, advanced infrastructure and technical capacity, and improved governance systems [*Srinivasan et al.*, 2012]. The previous chapter explored in detail the challenges that São Paulo must solve to overcome problems of governance; this chapter examines how São Paulo dealt with the remaining two drivers during an unprecedented drought. SABESP, the most significant water provider in the State of São Paulo, estimated that the drought was a 1 in 250-year event based on a calculated 0.004 probability of an "annual inflow equal or smaller to inflows actually observed in 2014"[23] [*SABESP*, 2015]. However, robust planning accounts for a wide range of possible futures and should provide several management options when drought occurs. We examine the actions taken in São Paulo in response to the drought based on the operations of the Cantareira system, and we further summarize a collaborative computer model that was presented at two public workshops to assess the possibility of applying a shared vision approach for (virtual) drought exercises in São Paulo.

[23] The Climatic Group at the CPTEC (Center for Weather Forecasting and Climate Studies) provides a different estimate based on accumulated rainfall records, they calculate this event to have a reoccurrence of 76 years given the probability of accumulated rainfall actually observed in 2013-2014 rainy season.

We build on the concept of models as boundary objects, presented in the previous two chapters, and we develop and test different policy alternatives. Although we were not successful in applying shared vision planning, we asked how drought planning could have been performed differently if a participatory process in São Paulo had been possible. In a second line of inquiry, we create system performance measures to calculate the impact of management policies on the reliability of São Paulo's water system, including consideration of costs to both users and the utility company. Given that São Paulo was affected by a drought of historical proportion, it was important to assess multiple plans to understand the reliability of the Cantareira under different management alternatives. Each plan incorporates different drought indicators, triggers and actions.

The chapter begins with Section 4.2 introducing background information on water challenges in megacities, with Section 4.3 focusing specifically on São Paulo. Section 4.4 analyzes São Paulo's drought event from the technical perspective of reservoir operations and the policies adopted to deal with the drought. Section 4.5 describes the mock SVM model prepared for the two public workshops to then illustrate in Section 4.6 how a collaboratively-developed model could support a formal and disciplined approach to assessing policy alternatives and tradeoffs. The development and formulation of this computer model is described in Section 4.6.1. In the absence of full public participation in São Paulo, our purpose is to provide a methodology for future collaborative drought contingency planning based on the use of a model. Hence, in Section 4.6.2 and 4.6.3 we establish a set of metrics for analysis as a proof of concept, and apply the model to compare drought action plans. Finally, Section 4.7 discusses conclusions and lessons learned.

4.2 Background to water problems in megacities

More than half of the world's population currently resides in cities. Forecasts suggest that this number will rise to exceed 66% by 2050 [*UNPD,* 2014]. Currently, 35 cities in the world exceed 10 million people, and the world's ten largest cities have populations of more than 25 million people. Despite decreases in per capita water demands in megacities in developed countries, total global water demands are forecasted to increase by 55% by 2050, even considering decreases in demands associated with irrigation [*OECD*, 2014]. The largest increases are anticipated to be in domestic water, water used in manufacturing, and water associated with power production [*UNPD*, 2014].

The ability to provide safe, reliable, and inexpensive water to large urban centers in developed countries was one of the marvels of the 19th and 20th centuries, but challenges still remain for expanding megacities both in developed and developing countries. Although many large cities reliably provide water to their residents during periods of normal climate and rainfall, most megacities (including Beijing, New Delhi, Mexico City, Cairo, Tokyo, São Paulo, and Istanbul) still face the specter of drought and its associated impacts. The authorities responsible for water supplies in these rapidly growing megacities must seek sustainable management strategies that can cope with growing water demands while addressing environmental challenges that place water supplies and public safety at risk. This chapter focuses on drought, one of the many potential threats to water supply in megacities, and on one city in particular, São Paulo, Brazil. However, to provide further background and context for our analysis, the next subsections explore the role that models have played in drought planning in the United States.

4.2.1 US drought and use of simulation models for planning practices

In the northeastern US, the drought of the 1960s was the largest on record, with significant impacts for most cities in that part of the country, including the major metropolitan region from Boston, Massachusetts to Washington, D.C. This and other major droughts in the 1980s had major impacts on water resources planning in the US. Water use curtailments were implemented throughout urban centers in the northeast, and a large portion of the population was exposed to management changes in an attempt to extend the water supply.

The US Army Corps of Engineers embarked on the "National Study of Water Management During Drought" in the late 1980s, with the goal of changing the way water supplies would be managed in the future. A significant contribution of the National Drought Study was the framework it provided for developing plans and drought action alternatives. Combining water planning principles, interactive systems analysis models, and collaborative planning, the National Drought study showed the effectiveness of using collaboratively-built computer models to quantify planning objectives and constraints so as to illustrate the tradeoffs between alternative plans. These plans can provide a consistent framework to prepare for and respond to drought events [*Shepherd*, 1998]. A drought contingency plan provides clear guidelines on how best to manage the demands and supplies of water during drought periods. Drought contingency plans are designed to minimize the impacts of water shortages on public health, consumer activities, recreation, economic activity, and the environment.

The National Drought Study framework described drought management measures as strategic, tactical, or emergency. Strategic measures include water supply planning, the building of storage capacity, long-term plumbing retrofits or system water loss reductions. Drought contingency plans are tactical measures, designed and evaluated prior to the drought but implemented when drought occurs. Emergency measures are taken when drought impacts exceed expectations, but some emergencies can be avoided with proper strategic and tactical planning. Examples of emergency actions include temporary water transfers, tapping into previously unused water sources, and water delivery with water trucks. These activities involve coordinating the roles of different stakeholders, including government, agencies, experts and the public, each of whom have different preferences and objectives.

4.2.2 The use of simulation models in drought planning

In the last century, inter- and intra-annually variability and uncertainties in water availability forced water professionals to develop concepts such as "safe yield" to ensure that water would be available when it was needed [*McCrodden et al.*, 2010]. In the 1980s, researchers used computer models to explore a variety of complementary metrics. They applied the concepts of reliability (the probability of system failure), resilience (how quickly a system returns to acceptable performance), and vulnerability (the likely magnitude of a system failure) to measure water supply performance [*Hashimoto et al.*, 1982]. These and other metrics characterize the variability of water availability and the extent to which systems at risk might fail in attempting to meet a constant water demand [*Hirsch*, 1979]. Whereas previous analysts assumed that past streamflows were a good predictor of future water availability and that streamflow statistics calculated from historical records would remain constant over time (stationarity), it is now recognized that the mean of (past) streamflow does not alone provide an accurate representation continued water availability because of changes in underlying physical phenomena such as climate (non-stationarity) [*Milly et al.*, 2008]. Rather than focusing on system yield or average streamflow measures, droughts water managers now understand that events more extreme than those seen in the past are possible. New York City, for example, maintains a 25% reserve storage should "a period occur which is drier than that experienced in the past (i.e., drought of record)" [NYC-DEP, 2012, p.16]. We break down the components of New York City's drought plan in more detail in Section 4.2.3.

Numerous studies have explored the steps necessary to create a successful drought plan. These steps typically include: 1) define planning objectives, 2) engage stakeholder, 3) design alternative drought mitigation strategies, 4) identify drought indicators, triggers, and actions, 5) evaluate plans, 6) select and implement the preferred plan, and 7) adapt and revise management plans as circumstances change [*IWR*, 1995; *Botterill and Hayes*, 2012; *Starkl et al.*, 2013; *Oertel et al.*, 2015]. A recent study of drought risk management reviewed the use of simulation models to assess performance metrics in drought planning and improve drought management [*Rossi and Cancelliere*, 2013]. The review highlighted the need for early drought indices, proper risk and vulnerability assessment, and adequate drought planning instruments to improve drought preparedness. As illustrated in the National Drought Study, the use of computer models can greatly facilitate drought preparedness. In addition, role-playing exercises, such as virtual drought exercises based on computer model simulations, can be extremely effective in establishing the importance of maintaining and revising drought plans over time with stakeholders [*IWR*, 1994b].

In short, droughts inhabit the intersection of diverse authorities, values, perspectives and needs. The National Drought Study recommended the development of drought contingency plans using a collaborative approach, engaging relevant decision makers, experts and stakeholders to ensure the most effective results. Environmental protection, health regulations, and safety risks may constrain the operation of water systems, thereby affecting reliability. Federal, state, and municipal governments may be involved in pricing, allocation, zoning, and land management decisions that affect demand. The primary role of water planners is to provide ample water to the public at an appropriate price and without compromising the long-term reliability of the water supply system. As noted by *Winz et al.,* [2009] in Chapter 2 discussion, many analysts favor incorporating simulation methods into stakeholder participation because simulations can provide visual displays of outputs and tradeoffs that, if well-designed, are intuitive and easy to understand. Next we explore the role of models in helping stakeholders determine suitable plans.

4.2.3 Shared Vision Planning for establishing indicators, triggers, and actions

One of the primary contributions of the National Drought Study was the development of Shared Vision Planning (SVP), a planning approach that engages stakeholders and decision-makers in building computer models to evaluate policy alternatives [*IWR*, 1995]. SVP combines three elements considered essential for effective drought response: well-tested planning techniques, effective public involvement, and a collaboratively built system model that integrates diverse knowledge from stakeholders involved in the process. SVP has been used in water resources planning for over a quarter century. It is an effective process for collaborative management, but all management parties must be committed to the collaboration. There is little reason to expect collaboration if any parties believe they can achieve a better outcome through alternate strategies such as lobbying, adjudicating, or stonewalling to preserve the status quo [*Werick and Palmer*, 2004].

The National Drought Study, among others, noted the need for a detailed framework for implementing drought actions [*IWR*, 1995; *Fisher and Palmer*, 1997; *Palmer et al.*, 2002]. This framework typically has three primary components (drought indicators, drought triggers, and drought responses) and two supporting activities (drought forecasting and monitoring/enforcement of response measures) [*IWR*, 1994b]. Drought indicators can be defined as any single observation or combination of observations that contribute to one's ability to identify the onset and/or continuation of a drought and to characterize its severity. Examples of drought indicators include streamflow, precipitation, reservoir storage, the Palmer Drought Severity Index, and other similar metrics [*Fisher and Palmer*, 1997; *Hayes et al.*, 2011]. A drought trigger is a specified value of a drought indicator that initiates a drought response. Drought triggers can be based on historical values, probability levels of past indicators, or points identified as optimal during the testing of response plans. Drought actions are activities taken or policies invoked that either increase water supply or decrease water demands. Water transfers, public drought awareness programs, water use curtailments, and changes in water pricing are all examples of drought actions. The usefulness of the overall framework depends on the accuracy of the drought indicators, the selection of appropriate triggers (calling for action when necessary, but also not initiating programs unless they are needed), and a robust portfolio of effective drought actions.

The New York City Drought Management and Contingency Plan 2012 is an excellent example of a plan that carefully identifies metrics, triggers, and actions [*NYC-DEP* 2012]. In addition, the plan is available to the public so that the rationale for decisions and operational assumptions made within the plan are clear. The plan contains a comparative analysis that is easily accessible to all those that are impacted. In the plan (Table 4.1), the objectives establish actions and procedures for managing water supply and demand during drought. The plan enables New York City's Department of Environmental Protection to maintain essential public health and safety and to minimize adverse impacts on economic activity, environmental resources, and the region's lifestyle. The primary drought indicator is the estimated probability that either of its primary reservoir systems (the Catskill/Delaware Watershed Reservoirs and the Croton

Watershed Reservoirs) will refill by June 1. The calculation of probability is based upon system storage, historical streamflows, real-time forecasts of streamflows, and forecasts of water demand. The drought triggers action are specific values of the probability: when the probability of a reservoir refilling before June 1 drops below 50%, the system goes on Drought Watch; below 33% initiates a Drought Warning; and a “reasonable probability” of the reservoirs being drained triggers a Drought Emergency. There are comprehensive actions associated with each of these drought levels (Table 4.1). These actions range from the implementation of a public awareness program to the enforcement of strict mandatory water-use curtailments.

New York City (NYC) has experienced a number of droughts of varying intensity over the last 60 years, including the years 1963-1965, 1980-1982, 1985, 1989, 1991, 1995, and 2002. NYC’s drought response planning is an example of how clear and well-defined metrics can guide both managers and the public to take mitigating actions before water problems escalate to a critical situation. These clearly defined drought responses and mitigation actions can be observed in past Drought Contingency Plans [*NYC-DEP*, 1988]. Such plans are indicative of the need for water authorities to act openly and transparently to elicit public support in minimizing drought impacts.

Table 4.1 NYC-DEP Drought Plan Summary (2012)

Indicator	Trigger	Action
Probability of Refill (by end of water year)	Less than 50%	**"Drought Watch" Declared** - Communicate with partner agencies and stakeholders - Implement drought awareness media campaign - Begin utilizing alternate sources (incl. Croton subsystem) - Prepare alternate sources (incl. Queens well field) - Expand leak detection and repair in the city
	Less than 33%	**"Drought Warning" Declared** - Communicate with partner agencies and stakeholders - Request voluntary water use restrictions by residents - Utilize alternative sources (incl. Croton subsystem and Queens well field) - Prepare additional alternative sources (incl. Chelsea pumping station on the Hudson River) - Expand leak detection and repair in the city - Minimize city outdoor water use for vehicle washing and landscaping
Probability of shortage	"Reasonable probability" that reservoirs will be drained/shortages will occur without mitigating action	**"Drought Emergency" Stages I - III Declared** - Communicate with partner agencies and stakeholders - Implement mandatory and increasingly conservative restrictions by residents (incl. vehicle washing and landscaping) and post conservation signs - Maximize alternative sources - Expand leak detection and repair in the city, including in private buildings - Minimize city outdoor water use for vehicle washing and landscaping - Implement emergency water utility rates

4.2.4 Stakeholder involvement in collaborative planning

As detailed in previous chapters, Integrated Water Resource Management (IWRM) has emerged as the dominant paradigm for managing water worldwide and is practiced in some 95 developed and developing countries [*UN-Water*, 2008]. IWRM is meant to integrate equitable and efficient management of water for attaining sustainable water use [*GWP*, 2012]. Whether it has achieved this aim or not, IWRM continues as the "centerpiece of world debate on water policy," and it has been said that IWRM "cannot be achieved without participatory processes" [*Priscoli*, 2004, p.226]. The EU Water Framework Direction, the National Drought Study, National Drought Commission and other major US federal standards acknowledge the important role of stakeholder involvement in water planning decisions. These directives all stipulate that the success of water management is contingent on the integration of public participation and the transparency of information.

It is widely believed that the complex and challenging exercise of creating and implementing of a drought contingency plan benefits from the informed consent and participation of those responsible for providing water, the individuals that are served by the water supply, and those that have regulatory responsibilities [*Palmer et al.*, 2013]. In short, we posit that providing safe, reliable and inexpensive water to the world's megacities poses more than an engineering and hydrologic challenge; it also requires early and sustained stakeholder involvement in a collaborative manner that allows them to work together during drought events to implement plans. This requires creating plans, but also, exercising them so that some familiarity exists when plans are put into action during a real drought.

4.3 Setting: The megacity of São Paulo

4.3.1 Urbanization and population rates

The population of the Metropolitan Region of São Paulo (MRSP) grew from less than 300,000 in the early 1900's to over 21 million in 2015 (Figure 4.1) [*Braga et al.*, 2006; UN, 2015]. The MRSP is the most populated metropolis in South America and among the most densely populated regions in Brazil, accounting for 10% of Brazil's population. In the last century, urbanization in the MRSP grew over 75-fold, and from 1960-1990 it was among the top 5 megacities in the world [*Angel et al.*, 2010; *World Population Review*, 2013]. The state of São Paulo is the economic engine of Brazil. Its Gross Domestic Product (GDP) is greater than the sum of the next 4 Brazilian states combined [IBGE, 2015b]. Meanwhile, development of the region's water supply has not kept pace with economic and population growth (Figure 4.2). The last major reservoir was built in 1982 for projected water needs in 2020 [SABESP, 1989].[24]

[24] Groundwater is also an important source of supply in São Paulo, especially for large commercial and industrial users. However, a significant proportion of wells are unlicensed and permitting records are spotty, making them an unreliable source for analysis of water supplies.

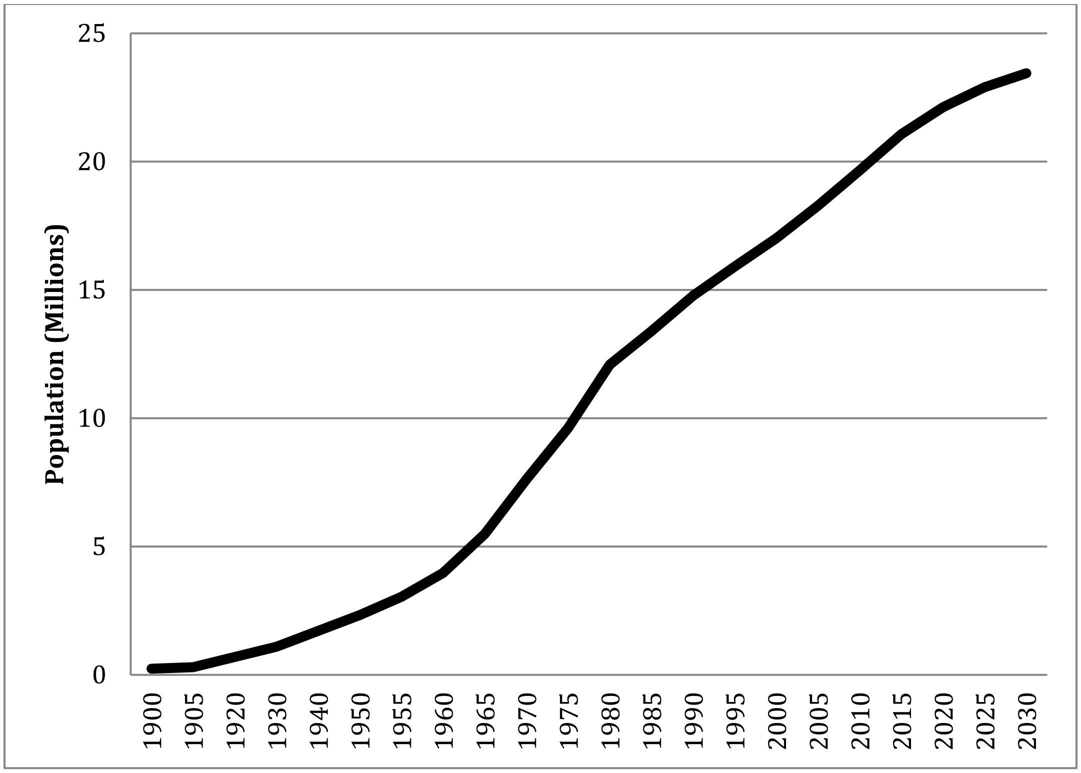

Figure 4.1 Population Growth in the MRSP [*Braga et al.*, 2006; UN, 2015]

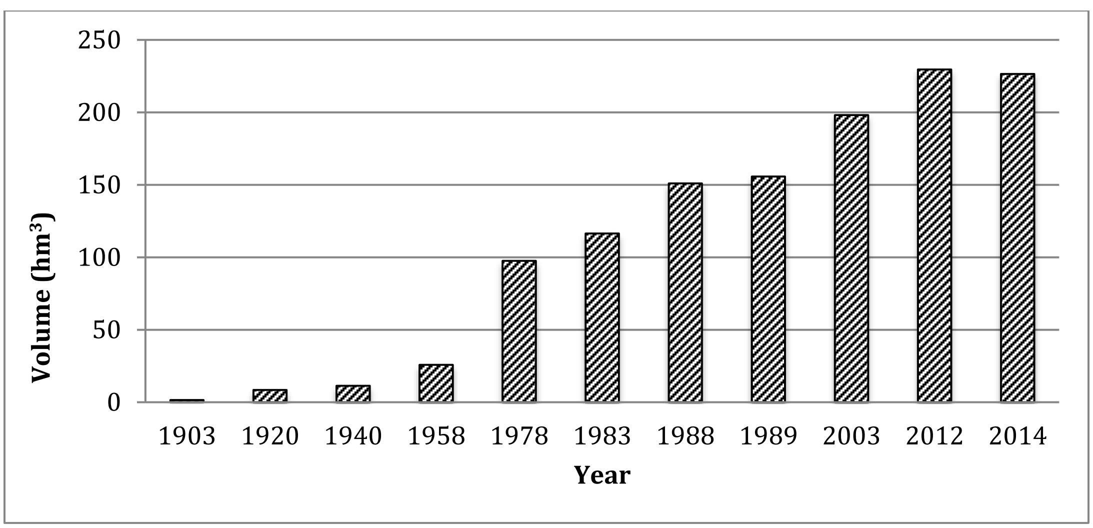

Figure 4.2 Water Availability to the MRSP (1903-2014) (Compilation from [*Whitaker*, 1946; *CEON*, 1967; *Porto*, 2003; *FPHES*, 2008; *SABESP*, 2015])

4.3.2 Water supply and the Cantareira system design

São Paulo responded to increasing water demands in the 1960s by designing and constructing the Cantareira System, a reservoir system that spans 15,320 square kilometers (5,915 square miles). The Cantareira System (Figure 4.3) was built in two phases between 1966-1982. It is composed of five rivers flowing into the Jaguarei-Jacarei, Atibainha, Cachoeira, and Paiva Castro reservoirs, with a total combined storage capacity of 981 cubic hectometers (hm^3) (when the use of dead storage is authorized by regulatory agencies, the new storage totals 1,270 hm^3). The system is a network of tunnels, a pumping station, and a small regulating reservoir. Water flows primarily by gravity, but is pumped in the final stages more than 120 vertical meters at Santa Ines to reach the water treatment plant prior to release to the MRSP.

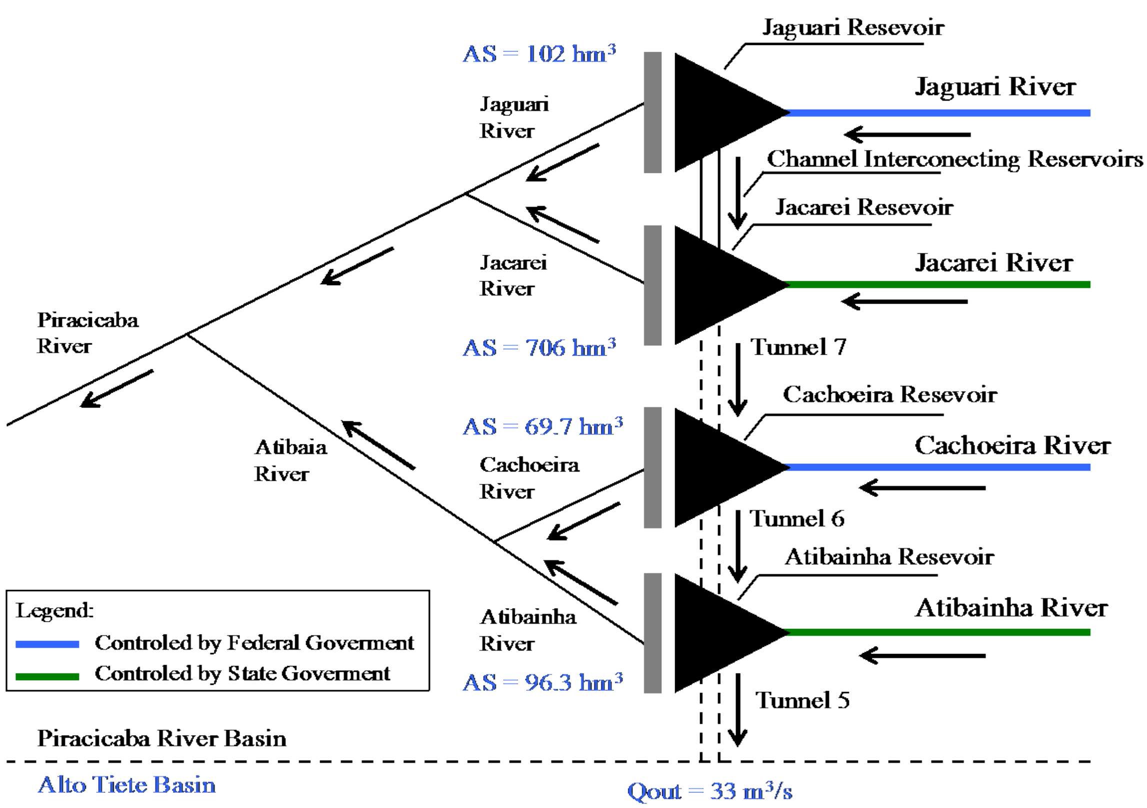

Figure 4.3 The Cantareira system of reservoirs and tunnels*

*Note the rivers that are of federal and state dominion.[25]

The system is typically responsible for supplying water to an estimated 15 million people, 9 million people in the MRSP and 6 million people in the neighboring Piracicaba, Capivari, and Jundaí (PCJ) river basins [IBGE, 2015a, IBGE, 2015b]. The Cantareira system is the most significant contributor of the 8 water systems for the MRSP, supplying 61% of its water. The next largest system, the Guarapiranga and Alto Tietê, provide 35%, while five other reservoirs (Rio Grande, Rio Claro, Alto Cotia, Baixo Cotia, and Ribeirão Estiva) provide the remaining water supply.

4.3.3 Water laws and institutional setting

Brazil's National Water Resources Policy (NWRP of 1997) [26] provides the framework for the country's water laws. Water is defined as a public good and is recognized as a finite natural resource with economic value. Water resource management must account for the multiple use of water and, in scarcity situations, must give priority to human and animal consumption. The river basin is the territorial unit for implementing and operating the National Water Management System. In addition, the NWRP states that water management must be decentralized and "rest on the participation of the public power, the users, and the communities." São Paulo's state law (Water Act of 1991)[27] was a model

[25] State rivers are regulated by state agencies and are defined as rivers that start and end within a state's boundaries. Federal rivers are regulated by federal agencies and are transboundary rivers at state or national borders.

[26] National Water Resources Policy (1997), Lei Nº 9.433, de 8 de Janeiro de 1997, Art. 1.

[27] São Paulo State Water Act (1991), Lei Estadual Nº 7.663, de 30 de Dezembro de 1991.

for the NWRP of 1997. In both state and federal water laws, the river basin is the territorial unit and the river basin committee (CBH) is the planning and deliberation unit for managing water. The role of CBH is central in Brazil's water laws. As the planning unit, the CBH was envisioned as an institution where members would share information, resolve conflicts, and build consensus regarding allocation and proper use of water.

Significant changes in water law resulted in water permit contracts being inconsistently negotiated in past years. A permit for a thirty-year interbasin water transfer of 33 m^3/s from the Cantareira system to the MRSP was granted in 1974 during Brazil's military government. The second water transfer in 2004 was negotiated under the new State and Federal Water Laws. Water allocations and operational rules for the Cantareira system were negotiated between the PCJ basin and the MRSP and authorized for a ten-year period by the two granting bodies, ANA (the National Water Agency) and DAEE (the State Department of Water and Energy), reflecting the state and federal dominion of the rivers that flow into the Cantareira Reservoirs. The agreement document, Decree 1213/2004,[28] determined monthly quantities and the operations of water transferred from PCJ to Alto Tietê (recall from Chapter 3 that the AT basin roughly corresponds with the MRSP). The process considered operational rules based on past demands in the two basins. When the allocations were made, it was estimated that the Cantareira system could provide water to PCJ and AT basins with 95% reliability.

[28] DAEE Decree 1213 (2004), Portaria DAEE Nº 1213, de 06 de Agosto de 2004.

During the drought of 2013-15, the deliveries anticipated from this system could not be met, and on February 10, 2014, the state governor instituted the Technical Advisory Management Group (called GTAG). The GTAG was required to convene at weekly meetings to advise how best to operate the Cantareira system during the drought. The group included representatives from ANA, DAEE, SABESP, and the Secretaries of the CBH-PCJ and CBH-AT.

4.4 Description of São Paulo drought planning process

4.4.1 SABESP's existing drought plans

In a document published in January 2014, titled *Rodízio do Sistema Cantareira 2014* (Rotation of the Cantareira System 2014), SABESP's technical team presented a plan "to implement water rotation in the areas covered by the Cantareira System." The plan defined rotation as "controlled shutting of water mains by sectors in a planned manner" and provided 3 rotation alternatives for water supply with the objective of "avoiding collapse" of the Cantareira system and to "ensure equitable services to the population" [*SABESP*, 2014d, p.4]. The plan proposed more than 10 operational and management actions, discussed operational logistics for emergency services, and identified the required tools and equipment. Another operational action was the possibility of reducing operating pressures to reduce water losses in the distribution system. The plan outlined the need to contact the municipalities affected by the drought, increase public awareness campaigns, engage the media, and respond quickly to legal complaints regarding economic losses to businesses. The plan was never executed and was not made public until August 2014, when a local newspaper reported that the state government had vetoed the measures identified in the plan [*Leite*, 2014]. As discussed in Section 3.3.2, state and national elections played an important role in the response to the drought. The short explanation for the veto was the prospect of the 2014 gubernatorial election. A more sophisticated and longer explanation involving continual denial of the drought was outlined in the previous chapter. In late September, the Public Ministry Prosecutor (*Ministério Público*) made the plan available to the public after it sued the state entities for negligence in dealing with the water crisis [*GAEMA-MP*, 2014].

A second plan titled *Plano de Contingencia II* (Drought Contingency Plan II), dated June 2014, was presented to GTAG by SABESP on June 20th, 2014, two days after ANA requested a clear statement of the operating procedures for the Cantareira reservoirs [GTAG, 2014b]. The Plan outlined the actions taken to reduce water withdrawals and preserve the Cantareira reservoir levels [GTAG, 2014a]. The actions adopted were grouped into three general strategies: 1) supplement flows from the Cantareira by transferring water from the Alto Tietê and Guarapiranga Systems, 2) institute the "Bonus Plan" to incentivize reduced water consumption,[29] 3) address water losses in the distribution system [*SABESP*, 2014c]. The most controversial action identified was the use of pressure reduction valves (PRV) to reduce pressure in the distribution pipes and reduce water losses (Section 3.4.2.3 details this strategy).

[29] The Bonus Plan was in fact a discounted rate in future billing cycles. It provided an incentive to domestic users to reduced consumption by giving a percent discount on their bill that would show as a "bonus" on the next billing cycle.

In September of 2014, as the hydrologic situation worsened, ANA asked SABESP to supplement this plan with rules for operation. Of specific concern was how to use the second dead storage volume that was to be made available in mid-October 2014. SABESP requested three postponements to deliver the updated document and eventually failed to meet the last deadline set for October 6 (for the implications of this action see Section 3.2.1). The incident occurred just weeks after ANA had officially announced its departure from GTAG due to its inability to reach an agreement with state authorities over reduction of water deliveries.

A final plan was released on April 30, 2015, titled *Crise Hidrica, Estrategias e Soluções da SABESP* (Water Crisis: Strategies and Solutions by SABESP for the Metropolitan Region of São Paulo) [*SABESP*, 2015]. The report reviewed the measures taken to reduce withdrawals from the Cantareira System. The plan discarded the rotation option, given its risks and impacts to the population, and identified a series of alternative contingent actions. This report included the measures from the Drought Contingency Plan II report as well as rules for the use of "Technical Reserves" or dead storage. Although the plan was not released until the end of April 2015, the success of achieving the 56% demand reduction observed between January 2014 and March 2015 was attributed to these actions. The plan listed a number of emergency construction works and actions to be implemented in the remainder of 2015.

4.4.2 SABESP's responses and actions

At the beginning of the drought, available water was defined and reported as the percentage of water in active storage divided by the total active capacity. "Active storage" is the water available above the gravity-fed outlet that can be drafted from the reservoir without pumps. The "total active capacity" is the total volume of active storage when the reservoir is full. In the Cantareira system, the active capacity also refers to the water volume permitted by decree for use. On October 2013, at the start of the rainy season, active storage in the Cantareira system was 363 cubic hectometers (hm^3), or 37% of the active capacity. Water deliveries remained at their full allocation amounts for several months. During this time, record low inflows into the system resulted in extremely low storage despite entering what was typically the "rainy season." On January 2014, active storage had declined to 219.7 hm^3 (22.4% of active capacity), and inflows registered roughly half of the historical minimum for that month.

The first water use reduction measures were implemented in March 2014, when reservoir levels dropped from 163 hm^3 to 131 hm^3 (16.6% to 13.4%) of active capacity. At that point, drought actions were taken including the implementation of a "Bonus Plan" for customers in the MRSP served by the Cantareira system. This plan provided a "bonus" in the form of price reductions on future water bills for those who decreased their water consumption. Water use reductions of 20% or more earned a 30% bonus, reductions of 15-20% were given a 20% bonus, and a 10-15% reduction was worth a 10% bonus [*SABESP*, 2014a]. These billing reductions would be effective only during the time of the drought and were suspended in early 2016.

In May, average Cantareira withdrawals decreased to 23 m^3/s and pumping of dead storage began in the Jacarei reservoir after ANA and DAEE issued a joint communication (ANA/DAEE nº 233)[30] to formally authorize the use of water from dead storage. As a result, storage jumped from 80 hm^3 (reported as 8.2%) on May 15 to 262.5 hm^3 (reported as 26.7%) on May 16. The additional 182.5 hm^3 were attributed to water that could be pumped directly from dead storage 1. This overnight increase in water availability caused some confusion, in part because plans for using dead storage 1 had been presented to GTAG in mid-March but had not been made available to the general public. Furthermore, SABESP reported percentages without actual volumes and calculated these percentages in an unconventional way by taking the total volume of water in active and dead storage divided by only the active storage (for a discussion on this confusion, see Section 3.3.1 in the previous chapter). Months later, in April 2015 a court order would force SABESP to clarify the actual storage volumes in the reservoirs as opposed to percentages.[31] Thus changes in reported water availability over time in the Cantareira system reflect three distinct factors: conservation actions, the actual amount of water taken from the system, and changes in both the amount of storage available and how it was reported.

In May of 2014, the Bonus Program was expanded to other municipalities outside of the MRSP served by the Cantareira. By August, ANA advised the dismantling of GTAG

[30] ANA/DAEE 233 (2014), Communicado Conjunto ANA/DAEE Nº 233 de 16/05/2014.

[31] *MP* of São Paulo, Civil Action suits No. 1013197-21.2015.8.26.0053 deliberation based on Court of Justice of the State of São Paulo, Judge Doctor Evandro Carlos de Oliveira (*Direito da 7ª Vara de Fazenda Pública).*

after its new proposed limits for the Cantareira were rejected by the Secretary of Water Resources and Sanitation (SSRH). Pumping of the second dead storage volume, which added 105 hm^3 in the Atibainha reservoir, began October 24, 2014. The percent storage reported again increased based on the newly available volume. The rainy season in southeastern Brazil usually begins in October and ends in March, but rainfall was much lower than normal by January of 2015. Given the situation, deliveries were reduced to a monthly average of 19.9 m^3/s in October 2014 and less than 14 m^3/s in several months in 2015 (Figure 4.4), with the daily minimum falling to 10.5 m^3/s on October 22, 2015.

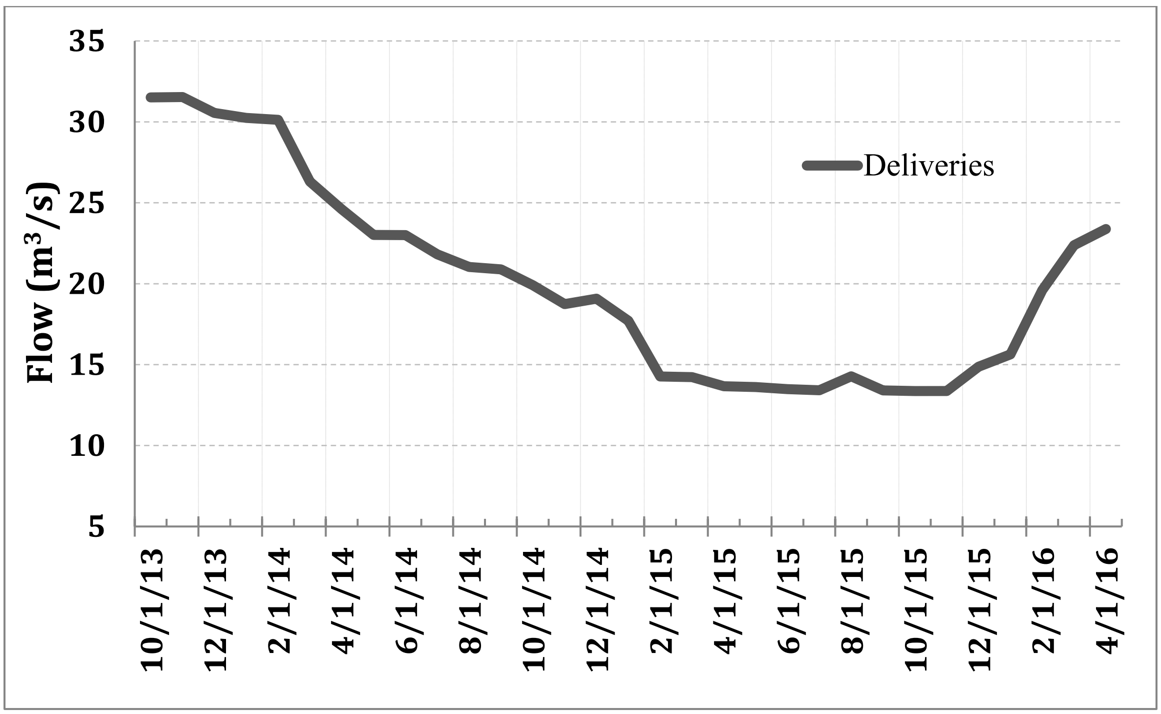

Figure 4.4 Monthly average water deliveries from the Cantareira system (October 2013-March 2016)

4.4.3 Transparency of the decision process

Motivated by public outcry, the *Ministério Público*-GAEMA, the Consumer Protection Agency, and the Commission of Parliamentary Inquiry (CPI) investigated the response to the drought. These investigations centered on SABESP's imprecise characterization of the drought, the lack of transparency in its decision making, and the lack of public engagement and education. The investigation conducted by the CPI of the municipality of São Paulo, for example, took over a year and included more than 60 meetings. In October 2014, the then-president of SABESP, Dilma Pena, was summoned three times but fail to make an appearance on the first two occasions. The CPI 2015 report concluded that SABESP neglected the population of São Paulo. It charged that Pena did not provide convincing answers about the water crisis, misleading the Commission about the number and frequency of residential water cutoffs. One conclusion of the investigation was that SABESP's contract with the MRSP needed to be regulated by a municipal agency because of "risk of being coopted and compromised independence of regulation" given favoritism from a state agency [*CPI*, 2015].

An unanswered question is whether the water rotation alternative was fair and adequately reported. The media and the public questioned whether it was possible to reduce pressure without turning water supply off completely. Several accounts from SABESP's technicians revealed that at many points in the city, adjusting the pressure was impossible and the only option was to turn the water on or off [*Leite*, 2015; *Sorano and Garcia*, 2015]. There are several accounts of SABESP's lack of transparency, but one revealed the large extent to which political interests at the state level played a role in the drought response: on November 18, 2014, the Washington Post reported how "the state government, which controls the water company, played down the crisis because of October's elections, in which the state's governor, Geraldo Alckmin, was reelected.

Critics say SABESP failed to keep the population properly informed and to introduce enough effective measures to reduce consumption", and that, "residents across São Paulo complain of regular shutoffs to their water supply while the state government and the water company deny that rationing is going on" [*Phillips*, 2014].

4.5 Workshop interventions in São Paulo

Uncertainty surrounding the drought and how São Paulo and regions supplied by the Cantareira would endure the 2014 dry season (starting in March) motivated Faculty from the School of Civil Engineering at the University of Campinas (UNICAMP), Brazil to host two public workshops. Falconi, Werick, and Palmer were key to initiating and coordinating the *International Workshop on Conflict Resolution and Water Scarcity in São Paulo* (May 2014) and the *Forum on Water Sustainability* (March 2015), where they presented the principles of shared vision planning. The goal of both workshops was to present a viable alternative illustrating how participatory modeling could be applied to São Paulo. During the workshop, we identified several challenges to public participation as the drought worsened.

4.5.1 May 2014 UNICAMP workshop

Faculty from UNICAMP, Brazil organized the Workshop on Water Scarcity in São Paulo on May 15, 2014 to explore ways to increase public involvement in SABESP's drought response. The workshop opened with a panel composed of Paulo Sergio Barbosa (UNICAMP professor), Antonio Carlos Zuffo (UNICAMP professor), Alexandra Faccioli (MP prosecutor), and Francisco Carlos Castro Lahóz (PCJ Consortium

Executive Secretary), all of whom voiced their concerns about lack of public confidence in how the drought was being managed. Lahóz, a long-time water activist and member of the CBH-PCJ since its beginning, said the major management institutions had failed to warn the public about the risk of shortages, even though many experts had predicted them a year before.

Falconi, Palmer and Werick designed an exercise involving all workshop participants to determine whether shared vision planning (SVP) could be used to manage droughts in the Cantareira system. We first presented the participants with examples of both successful and unsuccessful applications of SVP in and outside the US. A 'mock' shared vision model[32] (SVM) of the Cantareira system was presented by Werick in English (and translated and presented in the afternoon session by Falconi in Portuguese) to illustrate how a SVM of the São Paulo system might be used. Werick then asked participants to answer five triage questions [*Werick and Palmer*, 2004] designed to identify particular issues that could undermine a SVP process: 1) Can you imagine a better outcome – social, economic, environmental – from the use of SVP?; 2) Would SVP be undermined by the use of power by one party in another forum?; 3) Would all participants benefit from open discussion?; 4) Is there a non-water issue that must be considered along with water?; and 5) Could a competent team be assembled to do SVP, at least in a pilot study?

[32] Mock models are often created before a true SVM can be built in a collaborative process. Mock models are realistic, and they illustrate how expert, stakeholder, and decision-maker objectives and expertise can be connected, but they are not built collaboratively. Mock models help stakeholders imagine the steps and usefulness of a collaboratively built SVM.

These questions were informed by Werick and Palmer's 35 years of work in water and drought management and reflected a retrospective analysis of alternative dispute resolution techniques used in past case studies such as Boston, Seattle, Washington, D.C., and Portland in the US, and internationally, in Morocco, South Korea, and Peru. The results from the workshop were clear: the negative responses to Questions 2 and Question 3 indicated that participatory drought response was unlikely to be successful for Cantareira (the reasons for which are explored in Chapter 3). Although participants could imagine better outcomes using SVP, they agreed that it was not in the best interest of every party involved to have a more open decision-making platform such as the one offered by the SVM. These answers were reinforced by the notable absence of two main parties, SABESP and State water authorities, who had declined invitations to the workshop. It should be noted, however, that several State employees from SABESP and DAEE were present at the event, attending as individuals and not on behalf of their respective agencies.

4.5.2 March 2015 UNICAMP workshop

Ten months later, conditions had worsened. The UNICAMP's Vice-rector advisory cabinet of strategic thinking, PENSES, organized the *Forum on Water Sustainability*, which was held on March 17-18, 2015 at UNICAMP and streamed live online. At this second workshop, Werick proposed addressing the problems identified in the triage exercise from the previous workshop. Werick, Palmer, and Falconi proposed the use of SVP to collaboratively design a recovery plan from the drought based on virtual drought exercises. In this process, stakeholders could identify appropriate measures with the use of a SVM. The potential recovery of the reservoirs starting in March 2015 could gradually lead to restoring water deliveries as the drought subsided. The presentations by Werick, Palmer, and Falconi noted that three changes since January 2015 provided some hope this might happen: it had started to rain again at the end of February 2015 and public criticism of the drought response was stronger since the last workshop.

Moreover, two internationally respected academics who had long supported public participation and integrated water resources management had stepped into influential positions in the State of São Paulo in January 2015. Dr. Jerson Kelman, the first president of ANA, was appointed president of SABESP, and Dr. Benedito Braga, the current president of the World Water Council, had become Secretary of State for Sanitation and Water Resources (SSRH) in São Paulo. Kelman and Braga were professors of civil engineering with strong modeling backgrounds who had earned their doctorates in engineering at US universities. Both had been strong advocates for public participation, though it is unclear what their vision of participation looked like. Some contradictions between previous public statements and the way his position as World Water Council promoted shared responsibility is evident in Dr. Braga's statement at the G7 meeting [*Braga*, 2015]: "With almost half of the world's population facing water shortages, stakeholders and decision-makers across all sectors must assume shared responsibility to work towards water security." As shown in Chapter 3, the expressed views of shared responsibility did not lead to improved participation or transparency. It is possible, however, that Kelman and Braga believed that given the emergency situation, participation could get in the way of making rapid technical decisions.

A modified SVM was introduced in the March workshop and used to test the risk of failure under different options for restoring full water service before the reservoirs refilled. At the time, the water remaining in the Cantareira reservoirs was less than 152 hm^3 of the newly-defined active storage, which included the original active storage plus the two additional dead storages. Position analysis [*Hirsch*, 1978] using historical water supplies as test data in the SVM illustrated that water deliveries could be increased to 25 m^3/s with only a small risk of failure if the drought persisted. The model provided potential hedging strategies to manage the residual risk, but Palmer and Werick emphasized that public participation would be essential for these hedges to be successful because stakeholders would have to acknowledge and accept the risks involved. Once again, neither the State authorities[33] nor SABESP responded to repeated requests for their engagement in the workshop.

4.5.3 A challenging environment

Concepts of participation are principal tenets of Brazil and state of São Paulo's water laws. In fact, São Paulo's state law specifically mentions that the PCJ and AT river basin committees were created in part because high levels of water conflict would require more integrated and coordinated management. As noted earlier, strong participation by member institutions at these basins were central to São Paulo's water reform [*Abers and Keck*, 2006; *Castellano and Barbi*, 2006]. Nevertheless, the workshop participants

[33] One exception was the limited participation of a SSRH representative, who presented and then promptly left the meeting. More details on this are provided in Section 3.5.2.

agreed that stakeholders essential to the drought response felt collaboration and transparency would not be in the best interest of all parties involved, making collaborative planning infeasible.

News reports, official investigations, and testimonies reported at the workshops illustrated public concerns regarding lack of stakeholder involvement and misrepresentation of the drought in the MRSP. Many decisions were simply not reported.[34] SABESP drought plans that did surface eventually lacked specificity on reservoir operations and on the measures taken to reach agreement with other authorities as to official policies. The discrepancies and lack of information prevented any independent analysts from assessing the effectiveness of the response. The next section illustrates how an open, collaborative process can provide the opportunity for experts, stakeholders, and decision makers to test and improve the effectiveness of a wider range of plans.

4.6 Illustrative example of a Shared Vision Model's structured and disciplined approach to planning for the Cantareira system

This section uses the mock shared vision model (SVM), a systems dynamics model, prepared for the two public workshops, to illustrate how a collaboratively developed model could support a structured and disciplined planning process. The model was

[34] During the drought SABESP provided very little information. In several instances, the only reasons it released *any* information was due to a relatively new Freedom of Information Act, which allowed the public to demand information. Even under these circumstances, demands for crucial information (e.g. neighborhoods being affected by PRV, large consumers "fixed contracts", contingency plans for hospitals) was normally appealed all the way up through the courts.

developed with official data from ANA based on 84.5 years of monthly inflows to the Cantareira System, and it simulates reservoir levels and potential shortfalls based on changing demands (detailed next). Although the model was not developed in a truly participatory fashion, it was a prototype created to be shown to attendees at the workshop interventions.

The mock SVM can represent operational alternatives and their impacts on streamflows, deliveries, and storage. Because it contains both current and potential operating rules, it can illustrate the trade-offs between short-term management actions (such as curtailments) and longer-term system performance (systems storage and shortfalls). The model was presented as a proof of concept. In a real SVP model exercise, the public would be engaged in applying the model to identify operating policies and actions that reflected their priorities in water management. Ideally, the public would be engaged in a "virtual drought exercises", during which the choice of performance metrics and the particular tradeoffs were openly debated and revised. Such exercises not only improve the formulation of drought response plans but also create public confidence because stakeholders can participate in the exploration of tradeoffs and know the impacts and risks of each alternative.

4.6.1 Details of the mock SVM and post-workshop simulation model

The mock SVM used in the 2013-2015 workshops was developed by William Werick[35] to operate on a monthly time-step with estimated reservoir inflows from 1932-2016 [ANA/DAEE, 2016] and show ending reservoir storage (*S*) in a given month (*i*):

$$S(i) = S(i-1) + I(i) - R(i) - D(i) \qquad \text{(Eqn. 1)}$$

where *S(i)* is storage at the end of month i, and *I* is inflow, *R* is downstream release and *D* is demand during the indicated period.

The model was calibrated using the daily storage posted by SABESP for the period of 1/2004-6/2016 [*Coutinho et al.*, 2015]. To transform daily data to a monthly time step, storage volumes on the first of the month were taken, and monthly average inflows and releases were derived. Some of the major assumptions of the model are:

- Monthly rule curves for the two middle reservoirs, Atibainha and Cachoeira, were estimated based on observed storage levels over the calibration period.
- The model allows incorporation of dead storage into the storage capacities of Jaguari-Jacarei and Atibainha except in drought plan model runs. Although ANA/DAEE permitted the use of dead storage during the drought, on March 8, 2015 these authorities prohibited its future use.
- Base water demand is assumed constant at 33 m^3/s throughout the year. Water curtailments follow specified reduction scenarios for three levels of drought (Table 4.2).

[35] Werick developed the SVM for the workshops and later worked closely with Cambareri, Falconi, and Palmer to ensure that all members of the team could run or change the model as needed for testing future policy options.

Table 4.2 Management actions with varying restrictions from very severe to very mild

Curtailment		**Drought Level 2**	**Drought Level 3**	**Drought Level 4**
Very Severe Restrictions	Supply Reduction	23 m^3/s	18 m^3/s	13 m^3/s
	% Reduction	30%	45%	61%
Severe Restrictions	Supply Reduction	27 m^3/s	21 m^3/s	15 m^3/s
	% Reduction	18%	36%	55%
Moderate Restrictions	Supply Reduction	28 m^3/s	23 m^3/s	18 m^3/s
	% Reduction	15%	30%	45%
Mild restrictions	Supply Reduction	30 m^3/s	26 m^3/s	23 m^3/s
	% Reduction	9%	21%	30%
Very Mild Restrictions	Supply Reduction	31 m^3/s	29 m^3/s	27 m^3/s
	% Reduction	6%	12%	18%

4.6.2 Identification of indicators, triggers, and management actions

As previously noted, drought indicators, triggers, and management actions should be selected in a collaborative process using the model as a boundary object to facilitate interactions between modelers, decisions makers, and other stakeholders. The indicators, triggers and management actions used for illustrative purposes in this analysis provide suitable initial assumptions for collaboration and are based on case study experience. For example, stakeholders working on the first state drought plan for Georgia generated an extensive list of potential indicators that represent various water uses, and decision-makers and experts refined this list to identify the best indicators [*Steinemann and Cavalcanti*, 2006]. Trigger levels can then be defined based on percentiles of indicator values, representing the probability of occurrence. The approach was described by water managers in Georgia as “quantitatively and intuitively appealing” [*Steinemann and Cavalcanti*, 2006]. Percentiles can be easily interpreted, relating triggers to concept that are familiar to people such as probabilities of occurrence, making them an appropriate concept for use in SVP. Other methods exist, such as relating indicators to impacts, but these links are difficult to identify quantitatively [*Steinemann and Cavalcanti*, 2006]. The following indicators, triggers, and management actions represent an example of possible drought plan components for São Paulo, which could be tested and debated in a stakeholder engagement process.

The drought indicator included in the mock SVM is "days of supply remaining" (DSR), which was developed by Palmer in past studies [*Fisher and Palmer*, 1997].
DSR in a given month (i) is calculated by:

$$DSR(i) = \left\{\frac{S(i)+[(\sum_1^3 I(i+1))+(\sum_1^3 D(i+1))]}{D(i)}\right\} \qquad \text{(Eqn. 2)}$$

Where S is storage, I is inflow, and D is unaltered demand.

DSR is a composite indicator measured in days. It considers current storage levels and three-month forecasts of inflows and demands to determine how many days of water supply are left in storage, assuming constant demand. Three-month forecasts capture seasonal water availability for a given month; comparing the calculated DSR for the current month to percentiles from the 84.5 years of historical data captures how water availability in any month compares to long term availability in the past. This composite indicator is appropriate for São Paulo because the balance of inflow and demand can vary greatly (Figure 4.5), impacting water availability. It is ideal for use in SVP because it is easily understood by decision-makers and water users [*Fisher and Palmer*, 1997].

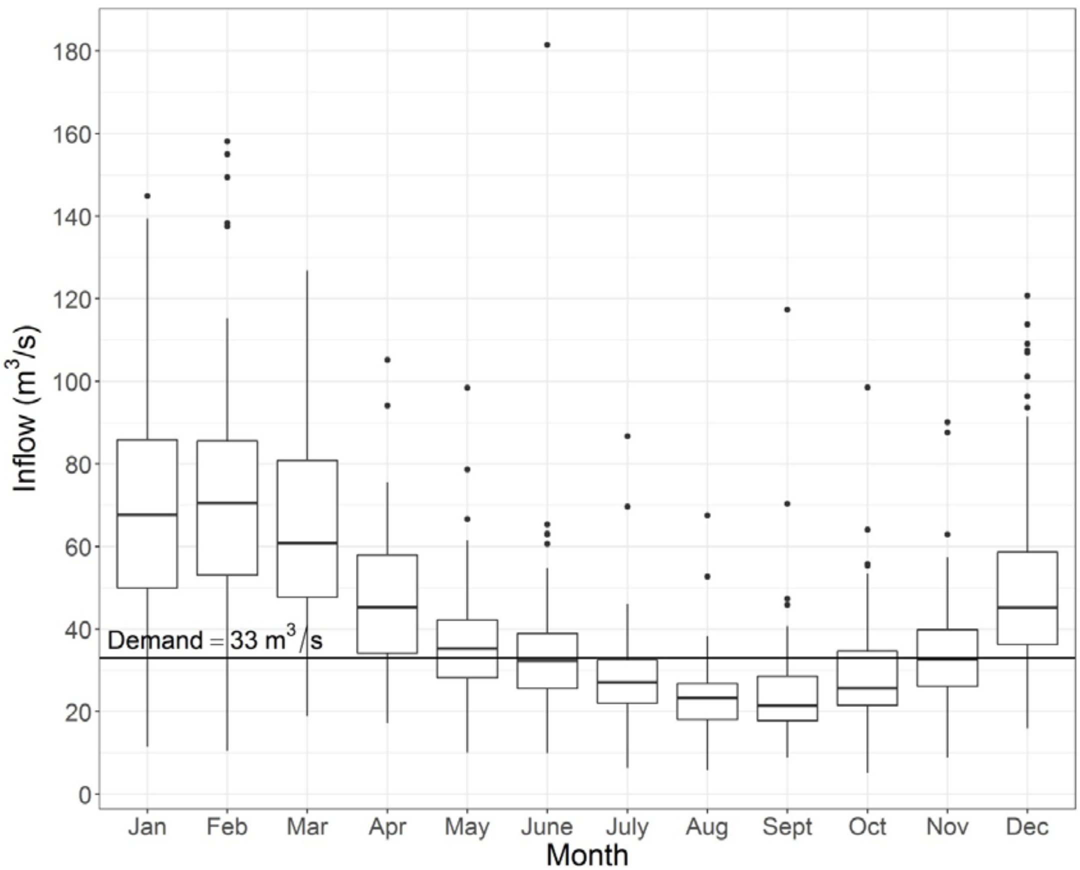

Figure 4.5 Summed monthly inflows into the Cantareira system for the 84.5 years of record compared. Current demand of 33 m^3/s is marked for easy comparison.

The historical series of DSR was created by running the model at a constant demand of 33 m^3/s, the estimated demand for the Cantareira system, with no management actions. DSR was calculated at a monthly time-step over the 84.5-year period, and 10th through 60th percentiles were taken for each month, resulting in monthly curves (Figure 4.6). Each drought plan has triggers defined at four decreasing percentiles that trigger four increasingly severe drought actions. In the model, DSR for each time step is calculated and compared to the triggers to determine the level of drought in the system. A range of percentile combinations was explored to select each drought plan's triggers (Table 4.3).

Table 4.3 Monthly DSR Percentiles for use as drought triggers

	Days of Supply Remaining (DSR)					
	10%	**20%**	**30%**	**40%**	**50%**	**60%**
Jan.	106	198	264	294	317	348
Feb	110	198	267	304	320	347
Mar.	102	185	260	297	320	347
Apr.	95	176	248	287	309	321
May	81	168	234	277	296	307
Jun.	64	155	215	262	282	292
Jul.	46	139	203	245	267	281
Aug.	34	128	198	235	254	268
Sep.	29	121	183	226	250	266
Oct.	32	129	205	234	250	272
Nov.	54	161	219	253	273	290
Dec.	75	187	247	273	293	322

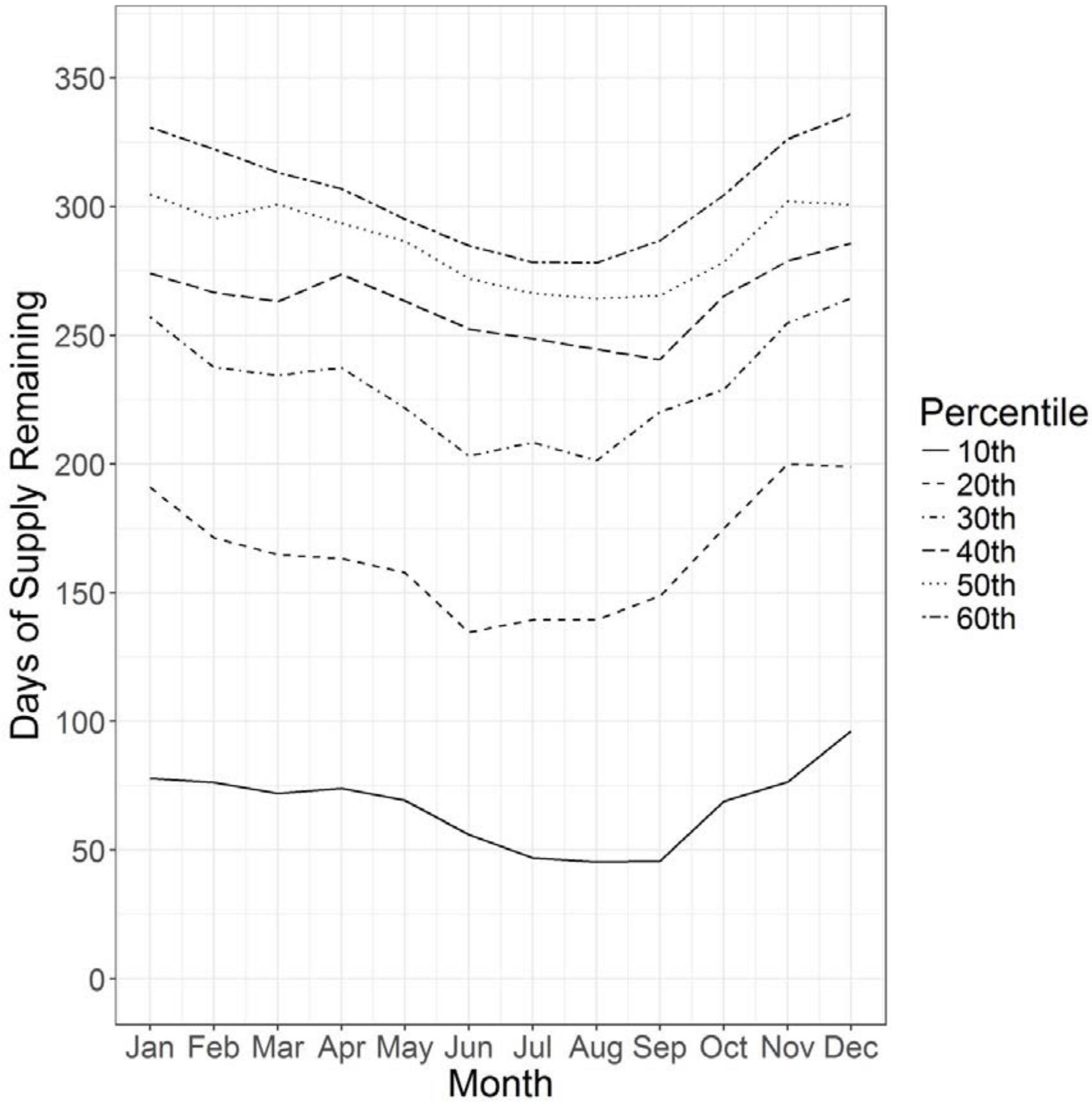

Figure 4.6 Monthly DSR percentiles for use as drought triggers for alternative plans

Management actions were characterized in the model as percentage reductions in demand. In reality, management actions are combinations of water use restrictions and other policy initiatives (e.g., pricing structure, monetary incentives, etc.), for which the effect on demand varies depending on regional circumstances. During the drought, actual deliveries were reduced by as much as 68% (to 10.5 m^3/s in October, 2015). The drought responses modeled in this example are within the range of known deliveries from the Cantareira system (10.5 m^3/s - 33 m^3/s).

Four levels of drought are included in each plan. Under drought level 1 ("drought warning"), managers would make internal preparations for a pending drought declaration but would not notify the public, resulting in no reduction in demand. Drought levels 2, 3, and 4 reduce deliveries with increasing severity, with the precise reductions varying by plan. Table 4.3 shows the restrictions associated with drought levels 2, 3, and 4 as they vary from very severe (23, 18, and 13 m^3/s) to very mild (31, 29, and 27 m^3/s).

4.6.3 Metrics of performance

Drought plans balance the severity of water reduction impacts against the frequency of preventative curtailments. Providing less water than customers demand is acceptable if it is rare and it contributes to lowering the most extreme impacts during the worst droughts [*IWR*, 1994a]. While we acknowledge that the risk of system failure and the inconvenience of having water use curtailed are value-laden metrics which can be perceived differently by different actors, the team chose the following set of performance metrics to use in our modeling effort as an example of how drought plans could be evaluated:

- System storage – minimum volume of stored water over the period of record and 10th percentile December storage (December is typically the month with lowest storage due to seasonal demand patterns);

- Reliability – percentage of time (monthly or annually) that the system meets full demand;
- Shortfall volume – the difference between the volumes of water demanded and delivered. Shortfalls resulting from restrictions are curtailment shortfalls and those resulting from water shortages are shortage shortfalls;
- Average months in drought – this represents the resilience of the system, i.e., how quickly it can recover from drought;
- Economic impact – losses to the utility from lost billing revenue and to the consumer for the lost value of water (detailed description below).

Minimal water use curtailments can be enforced without significant inconvenience, but as restrictions are intensified, the inconvenience grows. The inconvenience to the utility and the consumer can be quantified by estimating the economic value of the water supplied. When demand is curtailed, there are economic losses to the utility in the form of lost billing revenue and to the consumer for the lost value of water. Billing revenue loss is easily calculated as the volume curtailed times the price of water per volume. Consumer loss is more complicated and is estimated from studies on the difference between water price and demand [*Jenkins et al.,* 2003]. Following the methodology of *Jenkins et al.* [2003], demand curves are developed from an estimated price of water and assumed constant seasonal price elasticities that represent a change in quantity demanded for a change in price.

$$P = \exp[\left\{\frac{\ln(Q)}{\eta}\right\} + C \qquad \text{(Eqn. 3)}$$

$$C = \ln(P_{obs}) - \{\frac{\ln(Q_{obs})}{\eta}\} \quad \text{(Eqn. 4)}$$

Where P is the price at which quantity Q is demanded, η is the elasticity. C is the integration constant based on an observed price (P_{obs}) and an observed level of water use (Q_{obs}).

Integrating the demand curve from the quantity demanded given present water rates to a reduced delivery results in a total economic loss. Calculating economic loss for a range of reduced deliveries yields a convex economic loss function, where the rate of economic loss increases as deliveries decrease.

Information on price variability within São Paulo is limited. The price of water assumed in this analysis is R$4.32/m^3, based on average annual rates by sector from SABESP's tariff structure, weighted by total sectorial water use from 2013-2015 [SABESP, 2014e]. [36] Price elasticities were defined as -0.15, -0.25, and -0.35 for winter, intermediate, and summer months, based on estimates for urban areas in California, respectively [*Jenkins et al.,* 2003]. Urban California price elasticities were used as representative of São Paulo price elasticities for illustrative purposes given that their demand and elasticities parallel São Paulo's high and low rainfall season.[37] The summer elasticity (-0.35) suggests that water users will reduce consumption more than twice as

[36] Water rates do not vary year round, but rate structure does vary by sector (commercial vs. domestic) and with fixed-demand costumers. For simplification of this analysis the average annual rate was calculated for all consumers.

[37] Summer and winter seasons are inverted in the southern hemisphere, but high demand corresponds with summer (low rainfall).

much in summer than in winter with the same price increase. This is based on the estimated winter (-0.15) elasticity. São Paulo's maximum economic loss to consumers per cubic meter of water, R$1,250/m^3, was estimated from the price of bottled water in São Paulo, an R$25 cost for a 20 L container of water. Other values, such as the unit price of water delivered by truck, could also be considered, but bottled water was chosen here to represent a likely maximum. The resulting seasonal price and demand curves for the Cantareira system are shown in Figure 4.7. The section of the curves with zero slope represents the maximum cost of water. Integrating the demand curves for various reduced deliveries yields the economic loss curve in Figure 4.8.

The model results are illustrative for the São Paulo setting, since more precise data for that region are elusive. Several parameters (such as average prices, price elasticities, and economic losses) were derived from approximate values and are necessary proxies until better values can be determined. Although imperfect, these metrics provide insights into the nonlinear nature of the economic loss resulting from shortfalls. Further analysis could be conducted when improved estimates of alternative sources of water and price elasticities become available.

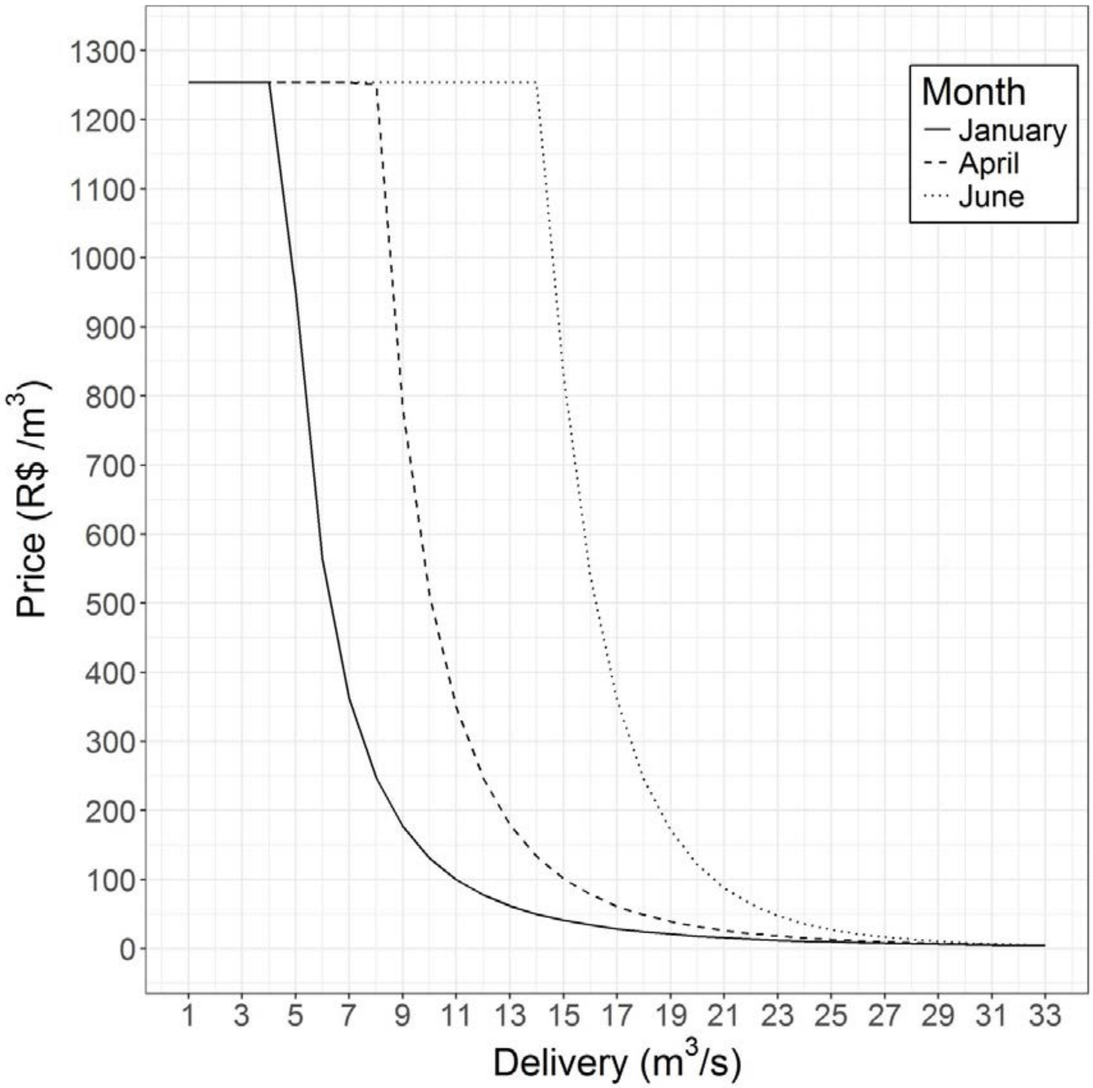

Figure 4.7 Price vs. demand curves for the Cantareira system reveal different price elasticities in different seasons (winter, intermediate, and summer)

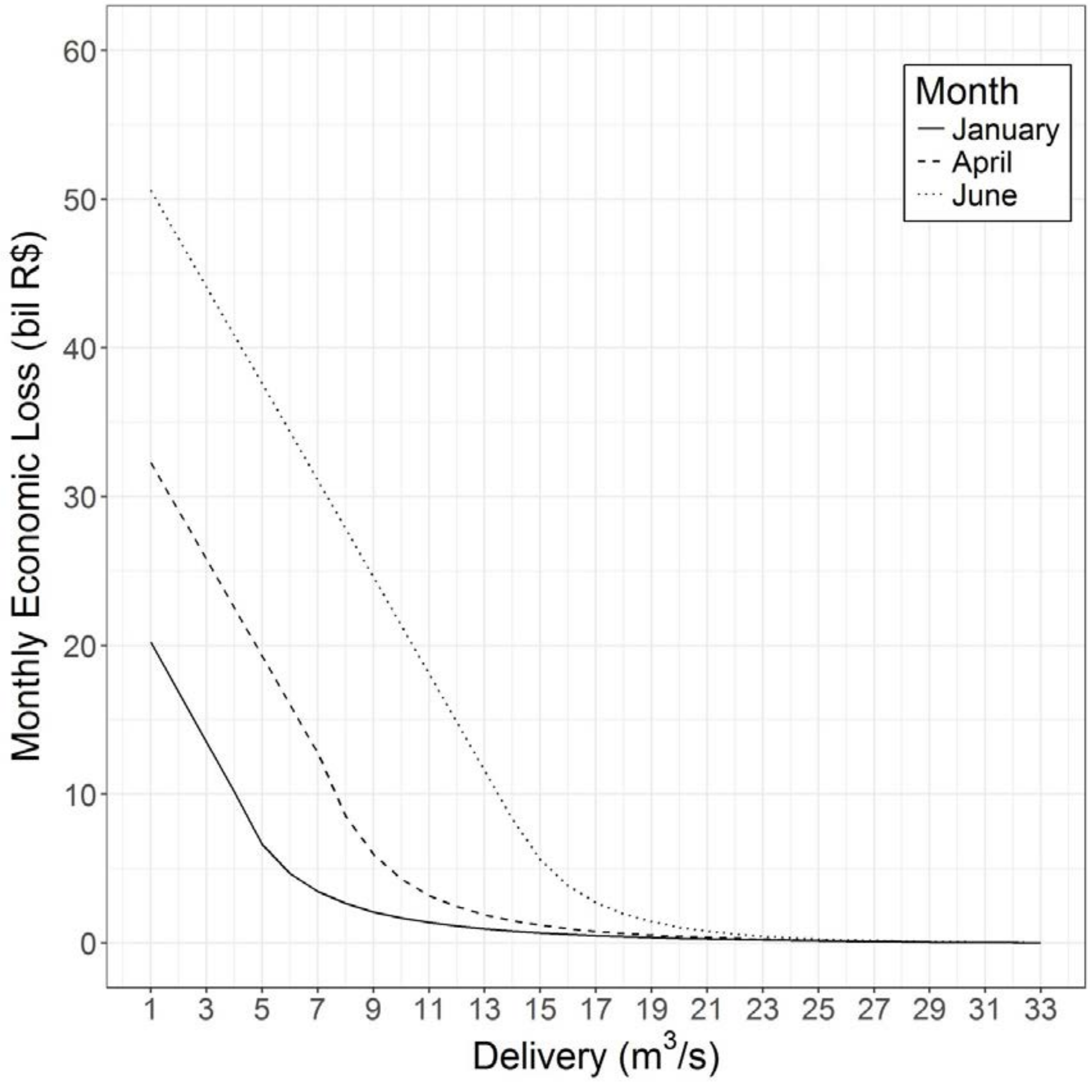

Figure 4.8 Economic loss for one month of reduced deliveries by season in three months representing winter, intermediate, and summer price elasticities

4.6.4 Example of tradeoffs for different operational policies of the Cantareira system

The goal of a drought plan is to balance the costs and inconveniences of seeking early curtailments in water demand against the public safety issues associated with imposing extreme water use restrictions to prevent the total depletion of a water supply. The timing and severity of restrictions determine the drought plan's effectiveness. In a SVP process, tradeoffs can be explored in real-time with the aid of computer models in what is known as a “virtual drought” [*Werick et al.*, 1994; *Keyes and Palmer*, 1995]. Examples of tradeoffs that may be explored in a “practice decision” or “virtual drought” are illustrated below by comparing ten drought plans with varying triggers and management actions. First, the effect of triggering restrictions early (at 50, 40, and 30 percentile DSR) or late (at 40, 30, and 20 percentile DSR) was calculated. Figure 4.9 shows a comparison of early and late actions based on different level droughts. Second, drought plan performance is compared for different management actions that range from very mild to very extreme restrictions. Table 4.4 presents simulation results showing how system performance is affected by different drought response plans.

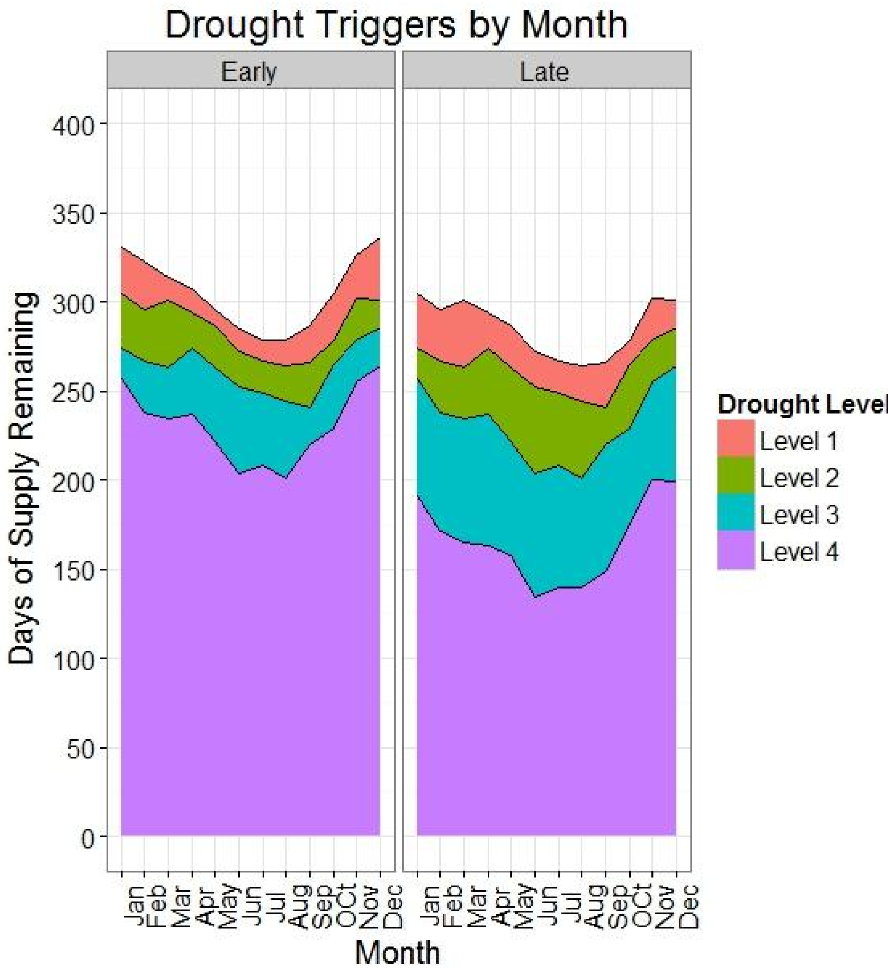

Figure 4.9 Comparison of early vs. late DSR drought triggers by month

Table 4.4 Results of alternative drought plans

Drought Plan	Description (Trigger, Reductions)	Storage (hm^3)		Failure Months	Shortfall Total (hm^3)	Avg. Months in Drought	Economic Loss (billion R$)	Reliability		% Time in Restriction
		Min	December 10%					Annual	Monthly	
-	No Plan	0	46	36	1748	-	329	0.91	0.96	-
1	late, very mild	0	425	12	3779	12	176	0.51	0.68	33
2	late, mild	0	518	6	4461	12	118	0.53	0.71	29
3	late, moderate	125	567	0	5195	12	56	0.54	0.74	26
4	late, extreme	310	595	0	5589	10	90	0.55	0.76	24
5	late, very extreme	399	627	0	6185	9	139	0.56	0.80	20
6	early, very mild	0	513	11	4676	12	138	0.44	0.63	37
7	early, mild	0	614	3	5715	11	96	0.46	0.66	34
8	early, moderate	220	646	0	6586	9	74	0.47	0.70	30
9	early, extreme	410	668	0	7002	9	116	0.47	0.72	28
10	early, very extreme	518	685	0	7629	9	185	0.47	0.76	24

Plans that initiate restrictions later (triggering curtailments when there are fewer days of supply remaining) increase reliability. Drought plans that initiate restrictions later also result in total shortfall volumes (the sum of curtailment and shortage shortfalls over the entire period) that are approximately 20% lower than drought plans with the same restrictions and early triggers. Despite the lower total shortfall volume, postponing actions places the system at greater risk of reaching low reservoir storage levels or potentially driving storage to zero and endangering the entire city, as shown by the minimum storage and 10th percentile December storage metrics. Early trigger plans maintain higher storage levels and recover from drought more quickly than the late trigger plans. Economic losses for the early and late trigger drought plans fall within a similar range, while the magnitude of the economic impact is dependent on the severity of the restrictions.

A comparison of these plans reveals tradeoffs that should be considered carefully. Drought plans with less severe restrictions have lower curtailment shortfall volumes, but result in very low (or empty) storage levels and, consequently, higher shortage shortfall volumes when these shortfalls occur. Of the ten drought plans, the only plans that result in failure months (when the system is unable to meet even the reduced demand) are those with mild or very mild restrictions. The system also recovers more slowly from drought when restrictions are mild, as seen by the higher average months in drought and percent time in restrictions, since storage levels will continue to fall until inflows substantially exceed deliveries. Longer periods with low storage correlate with lower reliability. In contrast, high restrictions levels help the system recover lost storage more quickly and have higher reliabilities and storage levels, but also cause high curtailment shortfall volumes.

An analysis of economic impacts helps identify the differences between very mild and very severe restrictions (Figure 4.10). As shown in Table 4.4, plans with very mild restrictions have high economic losses because they result in system failure (zero storage) in some years, and the economic losses associated with very low deliveries from shortage shortfalls are high. Economic losses are also high for very severe restrictions because, although planned, the deliveries are reduced significantly and frequently such that economic losses build from curtailment shortfalls even though no shortage shortfalls occur. Moderate drought plans result in the lowest economic losses because they avoid large economic losses from severe restrictions, but also reduce demand sufficiently to keep storage levels above zero and prevent expensive shortage shortfalls. It is important to note that the balance of economic losses from restrictions and shortfalls is dependent on the price and elasticity data used in the calculation of economic loss. The balance is also a function of water demands, so if base water demands increase, a different drought plan is needed to minimize losses.

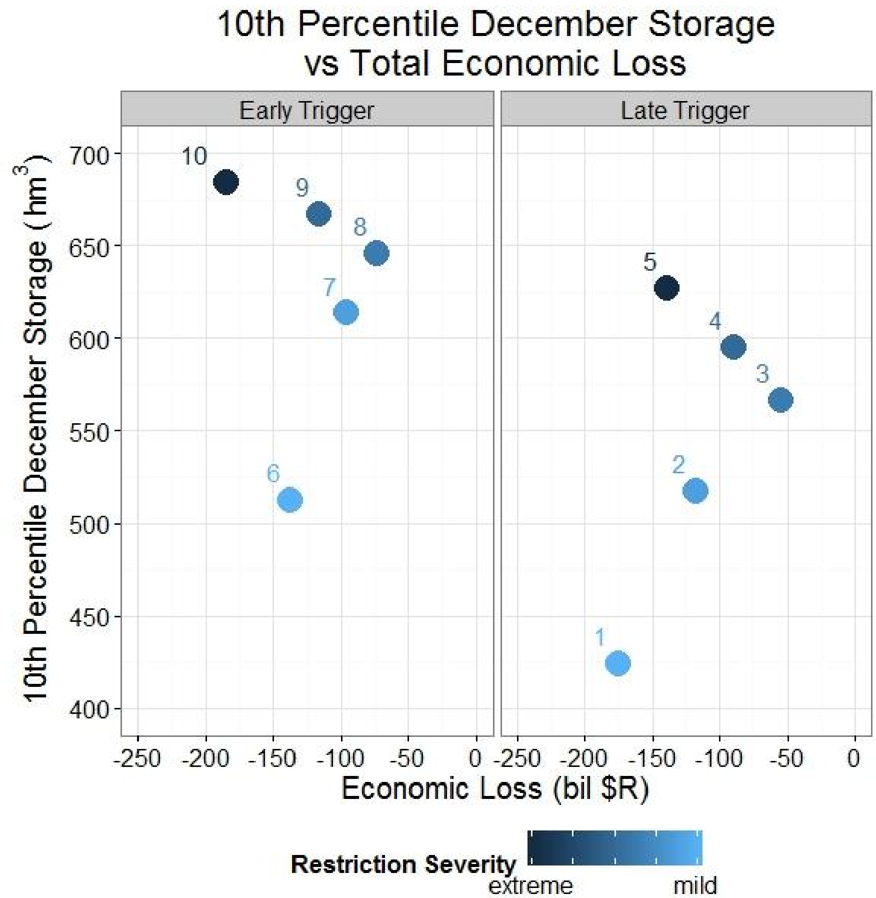

Figure 4.10 Tenth percentile storage in December vs. total economic loss

4.6.5 Identifying preferred drought action plans

Preferred drought action plans (that is, plans that are preferred by most stakeholders, plans that are not dominated by others) can be identified in a collaborative process that solicits stakeholder input. The identification of preferred plans requires iterative stakeholder engagement to determine: 1) the criteria to be used for measuring risk (e.g., shortfall volumes and reservoir levels) and inconvenience of shortfalls (e.g., economic impact), and 2) acceptable tradeoffs between the performance metrics. Other factors, like social and health impacts, could and indeed should be considered. In the absence of stakeholders, we chose the more easily quantifiable factors for illustrative purposes.

Based on our analysis, it is suggested that drought plans 3, 4, and 8 are among the preferred plans because they provide a balance between failure and shortfalls. These plans maintain over 10% active storage during the worst periods (Figure 4.11), much higher than the actual reported storage levels during São Paulo's drought, which benefitted from the use of dead storage. While ANA/DAEE permitted the use of dead storage from the Jaguarei-Jacarei and Atibainha reservoirs, the use of dead storage is prohibited in the future [*Andreu and Daruiz Borsari*, 2015], consequently this reserve storage is not used in particular model runs of drought plans.

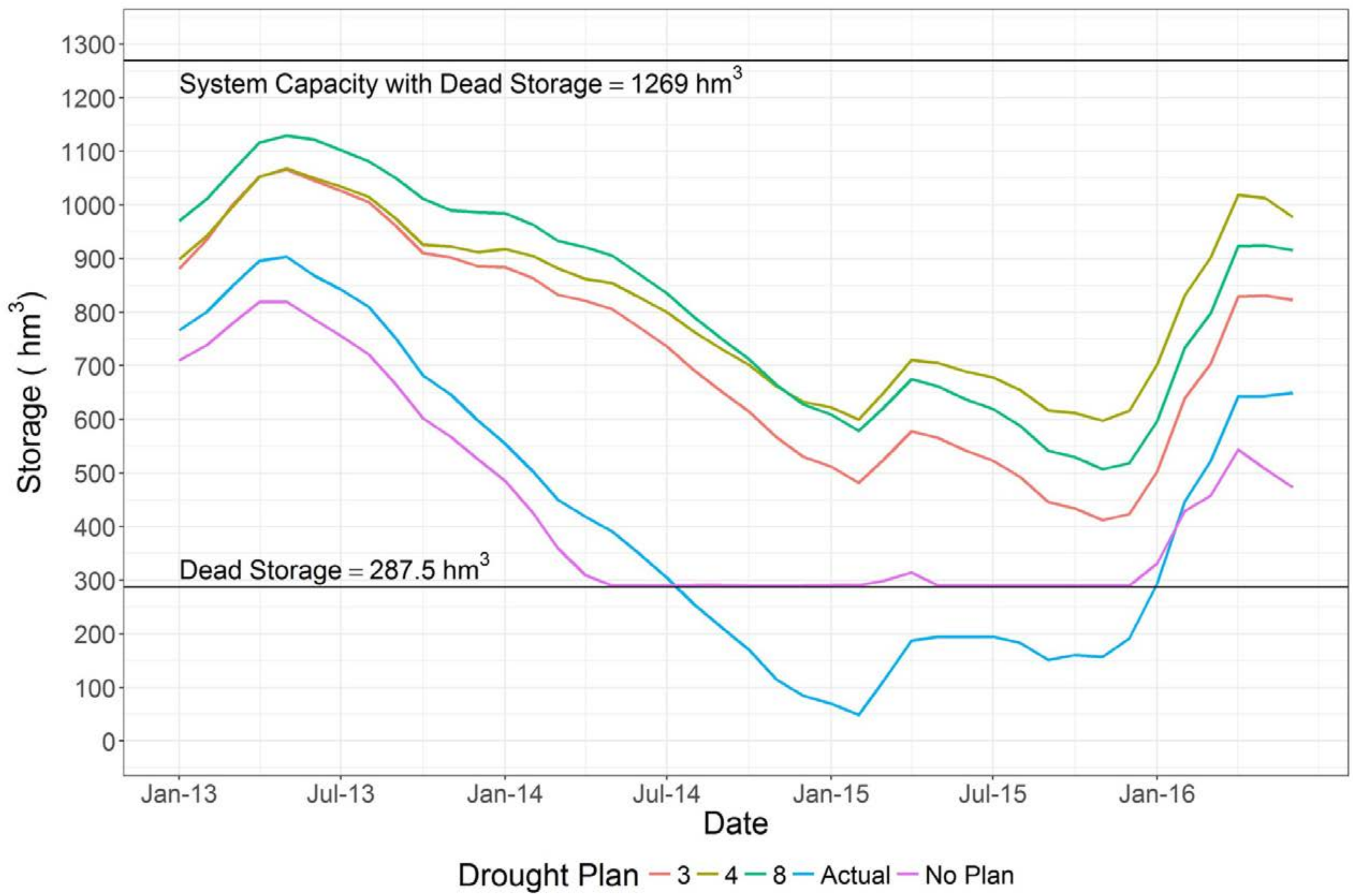

Figure 4.11 System storage for preferred drought plans and no drought plan during the 2013-2015 drought

Drought plans 3 and 8 have the same set of "moderate" management actions. However, by triggering restrictions earlier, drought plan 8 maintains higher storage levels than drought plan 3. Drought plan 4 enacts restrictions later, but by using "severe" restrictions, is able to maintain higher storage levels during drought than both of the moderately restrictive plans 3 and 8. These higher storage levels, of course, are due to larger curtailment shortfalls. Although based on this analysis drought plan 3, 4, and 8 appear promising, the optimal drought plan will depend on the tradeoffs and risks found acceptable by stakeholders and utility managers. Consumers should consider: Are they willing to accept the more severe curtailments of plan 4 if it means not facing more extreme and unplanned water restrictions and a lower risk of running out of water? Managers will make similar decisions, for example, one utility may be willing to accept more risk if they can minimize economic loss, whereas another utility may prefer economic losses to the risk of running too low on storage. In a real SVP process, these tradeoffs would be explored during virtual drought exercises where decision can be "practiced" openly with stakeholders, so the ultimate tradeoffs to each sector are well understood and negotiated. The more credible and legitimate the process, the more likely it is to succeed in an actual critical drought situation.

The performance of these drought plans is also highly dependent on inflows and base demands. Robust drought plans should consider impact of policies and operations over system performance in a wide range of possible futures, including increased demand (associated with household demands or population growth), changing regulatory measures and water permit allocations, increased environmental flow targets, or decreased inflows associated with climate change.

The length of the planning period will help guide the demands and inflows that should be considered. Short- and long-term impacts of adopted policies will have effects on system performance. To provide an example of planning for population growth, base demand was increased to 37 m^3/s and to 40 m^3/s and drought triggers were modified by multiplying DSR percentiles by the increased demand and dividing by the original 33 m^3/s demand, to determine DSR for the higher demand. If the same drought plans are implemented (with triggers modified as described) and the base demand is increased, the result is an increase on the percent of time in restrictions, the total shortfall volume, and economic losses (Figure 4.12). These results are significant since changes in starting conditions (supply or demand) mean changes in system operations to avoid greater risks. Moreover, minimum storage for each plan also increases with higher demand, likely because the lower DSR values cause more frequent restrictions (Figure 4.13). Utility managers and stakeholders must evaluate the risks posed by factors like population growth (example provided), aging infrastructure, permit allocations, environmental regulations, and climate variability to create appropriate metrics that determine if system performance is still acceptable or if alternative drought plans should be investigated.

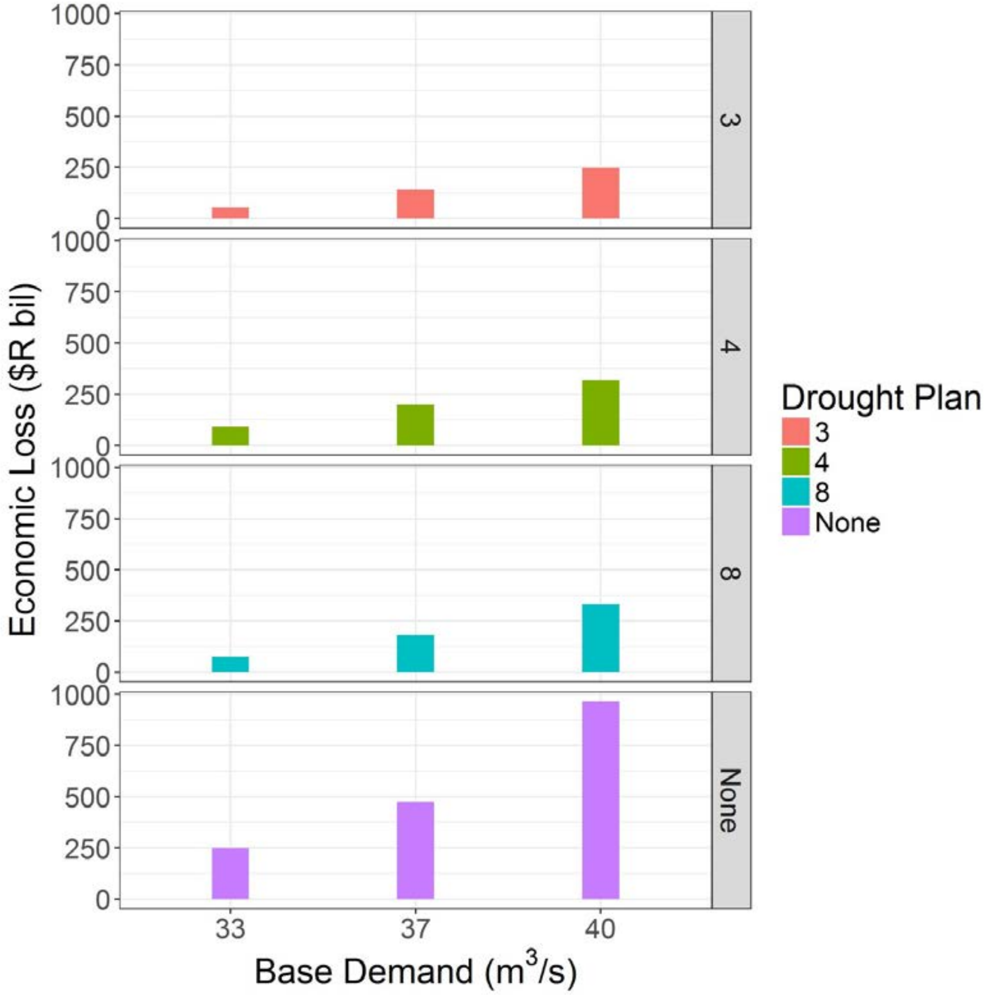

Figure 4.12 Economic losses at three levels of demand for four alternative management plan

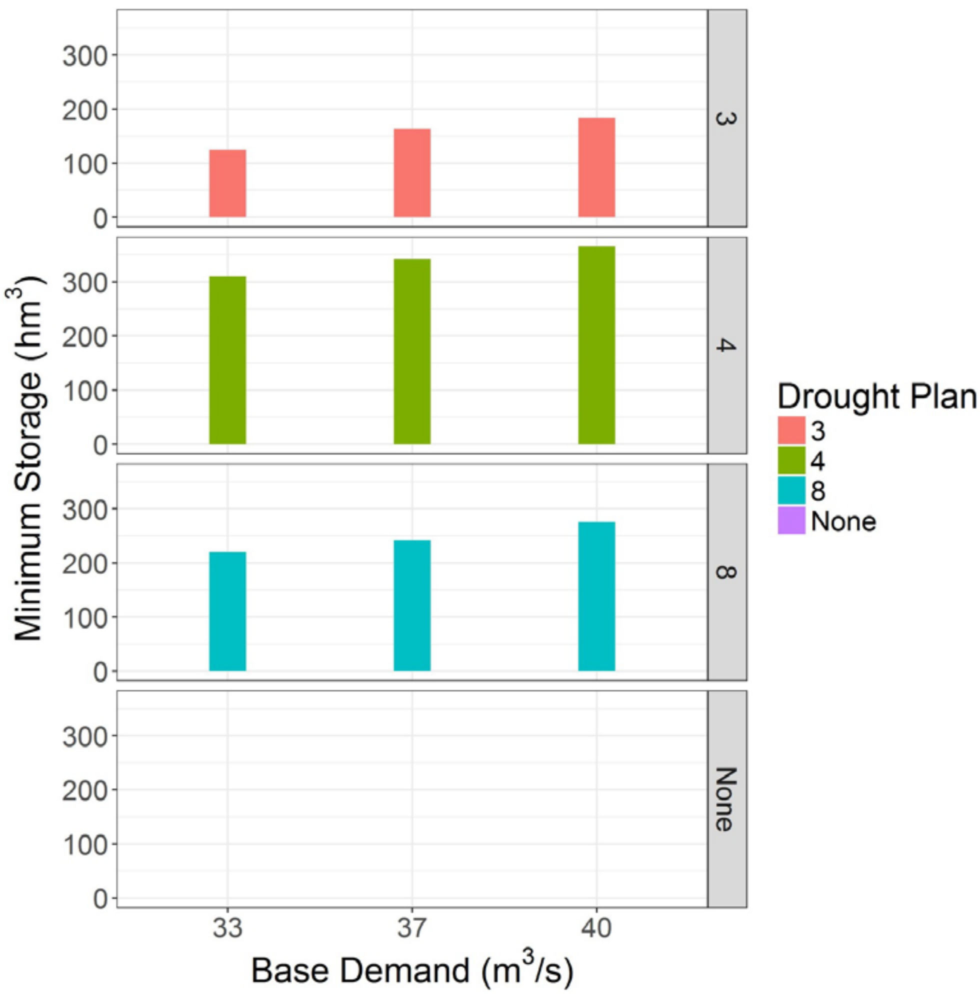

Figure 4.13 Minimum storage at three levels of demand for four management plan alternatives

This illustrative analysis did not include other portions of the São Paulo water supply system, nor other water supply options such as groundwater.[38] During the drought, SABESP was able to offset losses from the Cantareira to some degree by supplying water from the Alto Tietê and Guarapiranga systems: they reconfigured the distribution system so that gradually portions of the Northwest region of the MRSP normally served by the

[38] Refer to footnote 21 for more information on groundwater.

Cantareira could get water from the other reservoirs. Neither the benefit nor the cost of the non-Cantareira supply was considered in the above analysis. If SVP was applied in São Paulo, utility managers with knowledge of water transfers and other tactics to offset Cantareira system losses would need to participate in model development so that model results would more accurately portray system-wide impacts of drought management.

4.7 Conclusions and lessons learned

Megacities in the developed and developing world must prepare robust drought plans so that managers can handle changing conditions like the possibility of frequent and prolonged droughts. As in New York City's drought plans, managers should take the driest years of the historical record into account. The contribution of this chapter has been to analyze different management policies and their impacts on the performance of the Cantareira system during Brazil's historic drought of 2013-2015, a system whose reliability has been diminished by growing water demands over the past 20 years. Drought planning necessitates coordination and transparent policies that can be understood by those affected, including utilities, regulatory agencies, and the public. São Paulo's experience with drought planning provides several lessons on the many challenges faced by megacities as they strive to provide safe, reliable, and inexpensive water to the public. Many of these lessons are unique to São Paulo and are important given the critical situation it reached during the recent drought. Other lessons are more generalizable to the needs of other megacities facing water crises.

Effective drought response plans must balance difficult tradeoffs associated with management actions during extreme events. Here, those tradeoffs were the reliability of water supply and the frequency and costs of water curtailments. Processes like SVP have been used for 25 years in the US and abroad to allow decision makers, experts, and stakeholders to work together in determining the acceptability of tradeoffs as they build preferred plans. Once a plan is developed, virtual drought exercises allow managers and stakeholders to practice and update plans on a regular basis so they do not become reports that sit on bookshelves collecting dust.[39] In São Paulo, a series of management failures, including the lack of a clear, well-vetted drought plan and the absence of strong public engagement, resulted in a public that was misinformed about the risks. Drought plans existed for the MRSP, but some were dismissed and others were not disclosed until months after decisions were made. Furthermore, the rapid depletion of reservoir storage raised the question of whether storages could have been maintained (providing greater public safety and less inconvenience) had drought mitigation efforts been implemented earlier.

The time and effort required for stakeholder engagement mean that this type of participation fits best in the earlier stages of the planning process, rather than during the management of an evolving crisis. Consequently, the mock SVM of the Cantareira system presented at the two public workshops was not sufficient to catalyze a more collaborative drought response. The absence of immediate impact on drought management from the workshops may be explained, at least in part, by two factors. The

[39] Brazil is notorious for producing all kind of plans that never get implemented. The joke among Brazilians is that desk drawers are a graveyard for well-crafted plans.

first was a breakdown of the participatory process. The notable absence of SABESP and State water authorities from our workshops corroborated participants' impressions that that some entities essential to the drought response felt collaboration and transparency would not be in those parties' best interest. As a result, collaborative planning became infeasible in São Paulo, and not just because water resource managers failed to engage the public in a meaningful way, but also because they refused to be engaged by an active public. The second factor was a question of timing given a series of other non-water issues that converged to exacerbate the drought crisis (see Chapter 3 for institutional factors that exacerbated the drought). Our suggested interventions based on shared vision and virtual drought exercises foster collaborative responses through open communication, feedback, and practice, but none of these factors were present at the time of the workshops. The strength of virtual droughts is in their capacity to transform written drought plans into "working" and "evolving" documents, keeping these plans familiar during the years between droughts and allowing them to be adapted to changing climate risks and levels of demand. This chapter has shown how virtual drought exercises could have been done in São Paulo to simulate drought responses with vetted policy alternatives.

Finally, in a 2015 report, SABESP estimated (based on historic inflows) that the probability of experiencing a drought as extreme as that of 2013-15 was extremely low. It then suggested that managers could not realistically expect to find funding to build infrastructure capable of enduring such unlikely events [*SABESP*, 2015, p.11–12]. But to focus on infrastructure would be to miss the point. Water authorities in Brazil and elsewhere might learn from this unprecedented event in São Paulo. The water crisis was amplified by a lack of a vetted, tested drought plans with clear actions based on established indicators and triggers. Even when a long historical record is available for infrastructure design purposes, hydrologists agree that past flow distributions may not apply in the future. There is a plausible concern that the next drought may be more prolonged and severe than the 2013-2015 drought. Rather than relying on dead storage or other water supplies to manage future droughts, it makes sense to lay a sounder groundwork for responsive and agile resource management during critical events. These efforts will require improved communication channels for public engagement and vetted management response plans that do not simply rely on more supplies. Given a drought of this magnitude, São Paulo water authorities need to consider the impacts of short- and long-term policies. They need to weigh what timely actions may be taken to reduce risks and costs. In addition, they need to provide more transparency and clarity to the public who will be affected by those actions.

CHAPTER 5. CONCLUSIONS

5.1 Summary of objectives and research findings

At the core of this research are questions on how computer models support decision-making, how technical knowledge gets translated into policy, and whether meaningful participation in model building can strengthen adaptive governance and institutional capacity. Conventional wisdom holds that models are relevant to decision-making because better information helps reach better decisions. Empirical studies show that this relationship is not straightforward because when and how information gets used to support decisions makes a significant difference. Rather than assuming the utility of models, this study began from a different premise, working backwards to examine what makes models useful, when and how they are used to engage the public, and under what circumstances they are effective. There is a long history of models supporting water resources decisions. But to understand the impact of models and of the science and technical information they convey, one must understand the role of models in real settings, and that includes gauging how stakeholder engagement with a model based on local experience and realities, may provide more acceptable planning scenarios.

The research pursued the following objectives: 1) Characterize what makes models effective in engaging stakeholders in a participatory policy process; 2) Examine the case study of the Cantareira system joint water management in São Paulo to identify the institutional challenges to achieving improved participation and water governance; 3) Examine how collaboratively developed models can support a formal and disciplined approach to drought planning that incorporates stakeholders' concerns. To this end, two public workshops were organized to engage local stakeholders to showcase what collaborative modeling framework could look like in São Paulo. The objective and findings of each chapter are summarized below.

Chapter 2 introduced the five dimensions of participation and identified mechanisms for improving model effectiveness in public participation. It outlined a two-stage evaluation framework that provides an assessment of the mechanisms by which participatory computer models may be used to improve public engagement. In the two-stage framework, effective models were judged based on the concept of boundary objects. The analysis of models as boundary objects showed that diverse groups of people and organization can learn to talk to each other through models, building a new and shared syntax and improving understanding and interactions. The implications for model developers are that building flexibility and transparency into a model may help avoid artificially constraining the analysis. This research suggested that engaging stakeholders in model building is a process of constructing policy alternatives that are acceptable and binding. This is an approach that allows for accountable and transparent solutions and that involves the public in vetting policy alternatives.

Chapter 3 examined the case study of the Cantareira system joint water management in São Paulo, Brazil to identify the institutional challenges exposed during the 2013-15 drought. Since the passing of state and national water reform laws, river basin committees have created a platform for discussions and deliberations, a marked improvement over previous management approaches. However, the drought in São Paulo revealed the shortcomings of a water management paradigm that fails to take into account the political nature of water decisions. This chapter identified several institutional and structural challenges to fulfilling IWRM's promise of participatory water management.

The water supply system's reliability had grown vulnerable over decades of negligence and risky management decisions. Given the pressures and demands of a prolonged drought, a lack of transparency and information asymmetries limited the role of active participatory management in mitigating the crisis. Subsequently, state authorities concentrated decision-making power, and the more powerful players found ways to resolve their issues outside of the designed governance system. This situation eroded the role of the existing institutions that govern the Cantareira system. The undermining of their authority could have important effects in their ability to mitigate future water crises.

Chapter 4 provided an assessment of São Paulo's drought event based on documented data gathered through fieldwork and on a shared value model (SVM) of the Cantareira system. We analyzed the operation of the Cantareira system with the mock SVM under different drought indicators, triggers, and action management options. The analysis was based on a comparison of the tradeoffs between minimizing drought impacts to the system, the users, and the utility company. The findings were as follows. First, the system is stressed at the current demands, and higher water allocation permits could result in water conflicts in future dry years. Second, the nonlinear relationship between reduced deliveries and costs suggests that mitigating actions taken earlier in a drought are more effective. Third, any alternatives based on earlier but less stringent actions would preserve the reliability of the system but would also require stakeholder engagement at early stages. As a result, we concluded that drought planning requires defining – openly and transparently – what indicators will be used for systematic, early identification of drought onset, and what triggers will set management actions in motion to mitigate negative impacts.

Next, the conclusions are taken all together to analyze what we learned in terms of IWRM and water resource management based on São Paulo's case study.

5.2 Conflicting objectives in the era of IWRM

The level of disillusionment from key reformers was notable in the São Paulo case study. I interviewed and interacted with numerous players who had played an active role in promoting decentralized and participatory water reforms in federal (Brazil) and state (São Paulo) water laws. Progress had been made: rules and regulations had been written into law, governing and regulating institutions had been established, and yet, the frustration pointed to a vision of an improved water management that had not been realized. This can best be explained as a kind of disenchantment with the results of years of struggle and hard work to rewrite the rules of the game. My observation is best summed up by one particular interviewee who, when pressed for an explanation on why the current law was not working as intended, concluded that participation simply does not work in a country like Brazil. The underlying implication is that persistent political meddling over crucial decisions is a major reason for the failure of the reforms. To understand this disillusionment better, we must revisit the questions that motivated this work on the conflicting objectives of IWRM and the concept of water governance from two seemingly contradictory disciplinary perspectives.

The disillusionment observed in the São Paulo case study is evidence of one of the numerous contradictions found within the theory and practice of IWRM. The drought exposed the major shortcomings of placing complete faith in a technical paradigm that is devoid of political realities. The research presented in this dissertation has focused on the contradictions that stem from two seemingly inconsistent narratives of governance based on either techno-rational norms or local experience. For many experts, the worldview from a management and planning perspective stood in sharp contrast with the local autonomy required to implement the new water management paradigm.

As the conceptual framework of IWRM gains traction for institution building at all levels of the water dialogue, we must pause to analyze its limitations. The elusive concepts of the IWRM framework comes from a very linear and simplistic—almost naïve—view of how institutions gain authority over decisions. The depoliticized perspective of IWRM tends to emphasize the technical problems of managing water, thus generalizing the water problem to one of scarcity, striping water of its local context and geographical setting, and ignoring underlying historical and sociopolitical issues. The local experience provides a different perspective on IWRM, one rooted in structural and institutional problems that involve more than laws and regulations. These are things like the power to define the problem, the political weight to negotiate alternatives, and the authority to decide outcomes. IWRM acknowledges the growing importance of participation and water governance, but still is vague about the practical aspects of what governing means for managing water resources.

In much of the IWRM literature, the process and outcomes of policymaking are confounded. The result is two characterizations of policy, which tell different stories about who and what is involved in the decision-making process. The findings of this work provide important distinctions between policy as a process and policy as (prescribed) outcomes. A linear perspective assumes that policymaking has sequential steps from problem formulation, to evaluation of alternatives, to implementation. Findings from Chapter 2 on effective participatory models challenge that perspective. Policy as a process recognizes that stakeholder participation creates an iterative policy process where negotiations, diversity in opinions, and previously unidentified solutions are possible, even if contentious [*Mackintosh*, 1992; *Gordon et al.*, 1997; *Merrey et al.*, 2007]. Chapter 3 explored how technical perspectives of water governance can exclude concepts of political struggles and the (re)distribution of power, thus failing to address underlying factors that prevent participation and weaken governance. Finally, Chapter 3 and 4 together described policy as a process muddied by different perceptions and interests that need to be debated and contested in order to produce new bargained outcomes.

5.3 Broader impacts

Water governance provides a space where the two narratives of global norms and local experience may overlap. As argued in Chapter 3, water governance is best understood through more than one disciplinary lens. The lens chosen for this study was participatory models and the ways they engage diverse knowledge and participants in developing realistic policy scenarios. We explored what models for policy look like in a process in order to show how technology could be useful in building adaptive governance. Governance as a process questions how realistic it is to create grand objectives since circumstances can make new policy alternatives more or less acceptable. Technology itself is a sociopolitical process, often fraught with the very same problems it is trying to address. More work is necessary to carefully assess the mechanisms and conditions in which models work.

Water governance combines the laws and regulations within institutions, but also deals with the complexities of political and power struggles. The São Paulo case showed how models and technical information are not apolitical and can create insulated “technical” decisions. Participation was constrained by delayed or absent information which limited further scrutiny by all parties involved. During the unprecedented drought, São Paulo’s state government could have enlisted the existing institutions and basin committees to play an active role in solving the problem. It could have enabled them to act as the national and state water laws had intended them to. It did neither. This was not a question of laws, technical know-how, or proper planning. The existing institutions lacked the kind of authority, brokerage, improvisation, and decision-making power that strong water governance demands. This kind of “practical authority” comes from experience rather than laws and regulations [*Abers & Keck,* 2006; 2007].

Good governance is fluid and requires institutions that have autonomy and problem-solving capabilities to create adaptive policies as needed. Participatory models provide stakeholders a platform for coming to terms with the real trade-offs necessary to reach negotiated decisions even when contentious. Under new circumstances, like droughts, governing institutions need adaptive capacities that cannot be codified or generalized, because most circumstances are not predictable. The effectiveness participatory models needs to be evaluated more systematically in practice as they become extremely relevant to how issues are defined and framed in the policy process.

As the São Paulo case study showed, the ideals of a decentralized and participatory management paradigm contradict the tacit assumption that rational decisions and technical solutions will remain apolitical in the policy process. The participatory process opens "technical solutions" to discussion, introducing the possibility of political bargaining. For some, the idea of participation was less attractive since it would open the door to scrutiny. Reformist ideals were put to test when the local experience did not fit the neatly packaged plans and objectives of IWRM.

5.4 Future research needs

Given the interdisciplinary nature of global water issues, I have contended from the start that the best thinking in resource management comes from the interdisciplinary collaboration between academics, non-technical experts, and water management practitioners who bring different experiences from the frontlines of real world problems. More applied research is needed to deal with the disconnect between generating scientific and technical information and translating that information into policy. The findings outlined in this dissertation have raised questions to guide future work. There are many distinct narratives that could serve as a prism for examining the challenges faced in global water problems both of management and governance, and to look for areas of overlap. The following questions are related to the institutional implications of the present study, which need to be better understood:

1. In what ways can we think about resource management problems as problems of collective action and improve understanding of the role of trust?

2. What are useful ways to think about the individual and the collective? How can institutions change to incentivize the individual to act in the benefit of the collective?

2. How does our understanding of collective action improve mechanisms for creating trust, reciprocity, cooperation and accountability in institutional building?

3. How do we create or revise institutions to reward collaboration rather than favor a small group of well-positioned stakeholders whose interests are not aligned with the general social interest?

4. With water sustainability in mind, how do we define the multiple dimensions of science and technology adoption for new policy alternatives?

5. What steps are necessary to translate findings on governance into the context of other global norms for resource management, such as sustainability?

Society influences the creation of science, which questions are deemed important, and which problems become relevant. Therefore, an interdisciplinary perspective is needed to answer these questions. Many of these questions do not seek hard and fast rules but rather new perspectives to shine a light going forward. The need to engage technical and non-technical actors is necessary and it will be possible by reaching across disciplines to overcome the language, cultural, and rhetorical barriers that prevent new solutions from emerging [*Schoenberger*, 2001].

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APPENDIX A

A.1 Rigor of Evidence

Chapter 2 analyzes five case studies based on the evidence the authors provided. This appendix lays out the spectrum of evidence used to assess the methods presented by each author to substantiate their claims. This spectrum is one of the limitations of the evidence available for case study analysis

Spectrum of Rigor		
Most	**Intermediate**	**Least**
Neutral third party evaluations	Public or peer evaluations	Author's assertions but with no other evidence
Self-reporting if anonymous answers are made available	Open polls	
Quoting from anonymous surveys and questionnaires	Non-identifiable interviews	
Any physical evidence (e.g., photographs, MOU, model and database available for download)	Surveys and questionnaires with tendency for biases (e.g., phrasing of questions or non-anonymity)	

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APPENDIX B

B.1 Methodological Observations

Below, I provide a list of the 33 interviews carried out between December 2011 and Dec 2015. The number of interviews exceeds the number of interviewees given that some people were interviewed on more than one occasion. Measures are taken to protect the interviewees' confidentiality. Interviewees are identified by their job title or association with the water basin committees, which reflects their function at the time the interview was carried out.

Interviews were complemented by participation and observations in formal and informal meetings at the national, state, and river basin level. These were invaluable sources of information that allowed me to contrast the participatory approach as depicted by the books and interviewees with the real participatory practices. Finally, document analysis was a third source of information used to triangulate interviewee's accounts and observations. Document analysis provides primary evidence of dialogues and decisions made between institutions at different moments of the process as recorded in their formal reports or documents. Documented sources are central to verifying events and aligning different perspectives or recollections of the same event. Meeting attendance allowed me to observe the mechanisms of participation and deliberations; documental analysis constitutes a supplementary line of evidence.

B.2 Interviews:

Identifier #	Date	Interviewee	Location
1	1/11/11	Water resources engineer	Curitiba, PR
2 & 3	1/14/11 9/25/13	Water resource university professor	São Paulo, SP
4	1/17/11	University professor	São Paulo, SP
5	1/19/11	University researcher	São Paulo, SP
6 & 7	1/19/11 3/28/14	Water resource university professor	São Paulo, SP
8	1/20/11	Water resource university professor	São Carlos, SP
9	1/21/11	Water resource university professor	São Carlos, SP
10	1/21/11	Water resource university professor	São Carlos, SP
11	1/21/11	Water resource university professor	São Carlos, SP
12	9/17/13	Public Prosecutor	Jundai, SP
13	9/17/13	Piracicaba River Fisherman Club	Jundai, SP

14	12/3/13	PCJ Consortium	Americana, SP
15	12/5/13	PCJ Consortium	Americana, SP
16 & 17	2/28/14 3/25/14	Technical Analysts	Piracaia, SP
18	3/9/14	Water engineer	Americana, SP
19	3/21/14	Water resource *técnico*-State	Piracicaba, SP
20	3/27/14	National Water Agency Political Appointee	Valinhos, SP
21	4/10/14	Water resource *técnico* - Federal	Phone Interview
22	4/11/14	Water resource *técnico*-State	Piracicaba, SP
23	4/11/14	Water resource *técnico* - State	Piracicaba, SP
24	4/28/14	Social science university researcher	Phone Interview
25	5/12/14	University professor	Campinas, SP
26	5/30/14	SABESP Employee	Atibaia, SP

27	5/30/14	SABESP Employee	Atibaia, SP
28	6/15/14	National Water Agency *Técnico*	Brasilia, D.F.
29	6/15/14	National Water Agency *Técnico*	Brasilia, D.F.
30	6/15/14	National Water Agency *Técnico*	Brasilia, D.F.
31	6/15/14	National Water Agency Political Appointee	Brasilia, D.F.
32	4/8/15	Water Alliance	Phone Interview
33	8/21/15	National Water Agency *Técnico*	Phone Interview

B.3 Meeting Attendance:

1. 1st PCJ Committee Inter-chamber meeting September 17, 2013
2. PCJ Consortium— September 27, 2013
3. *Ministério Público* Public Hearing—October 3rd, 2013
4. PCJ Consortium— December 2, 2013
5. PCJ Committee 127th *Câmara Técnica de Monitoramento Hidrológico* (CT-MH)—November 29, 2013
6. PCJ Committee 129th CT-MH—January 31, 2014
7. ANA Public Hearing for Cantareira Water Permit Renewal—February 10, 2014
8. PCJ Committee 57th Ordinary *Câmara Técnica de Integração e Difusão de Pesquisas e Tecnologias* (CT- ID)—February 17, 2014
9. PCJ Committee 130th CT-MH—February 28, 2014
10. PCJ Committee Water Management Framework Seminar—March 19, 2014
11. PCJ Committee 13th Ordinary Meeting—March 27, 2014

12. PCJ Committee 131th CT-MH—March 31, 2014
13. PCJ Committee 58th Ordinary CT- ID—March 14, 2014
14. Institute Fernando Henrique Cardoso. Water Governance, Management, and Challenges—April 18, 2014
15. PCJ Committee 132th CT-MH—April 30, 2014
16. PCJ Committee 2nd Ordinary Meeting, Drought Technical Group—May 14, 2014
17. International Workshop in Water Scarcity and Conflict in São Paulo—May 15, 2014
18. PCJ Committee 133th CT-MH—May 30, 2014
19. PCJ Committee 134th CT-MH—June 27, 2014
20. PCJ Committee 135th CT-MH—July 31, 2014
21. PCJ Committee 136th CT-MH—August 29, 2014
22. PCJ Committee 137th CT-MH—September 30, 2014
23. ANA and DAEE meeting to consolidate water restriction in PCJ—October 18, 2014
24. PCJ Committee 138th CT-MH—October 31, 2014
25. PCJ Committee 139th CT-MH—November 30, 2014
26. Forum of University Rectors—February 10, 2015
27. Sustainability Forum—March 18-19, 2015
28. Braudel Institute of World Economics. The Water Crisis after the Rain—June 2, 2015
29. Institute Fernando Henrique Cardoso. Facing the water crisis: A debate with Jerson Kelman, president of SABESP—June 8, 2015

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APPENDIX C

Interview Sample Questions

Interviews were semi-structured and were most often open ended. These questions are only a small sample of questions that any interviewee could have been asked.

Participation Group: Technical council members

Questions

1. Where you present during the 2004 Cantareira Negotiations?
   If so, what was the nature of your participation?
   If not, when did you become a committee member?
2. How are [CT-MH/CT-ID] Technical Council members informed of technical matters in the basin?
3. Is this information readily available and where does it come from?
4. Who determines what information to requests from [consultants/researchers]?
5. Did you participate in the use of Decision Support Systems (DSS) in the past? When and how often?
   If yes, continue to Model Use and Model Effectiveness section.
   If no, have you heard of DSS? In what context? (Skip section on Model Use)
6. What other information did you use to help you make decisions allocation decisions?

Model accessibility:

7. What was the nature of your participation (When/where/what did you participate in)?
8. How is the DSS actually used? All its functions are used or it is only used for some functions? Why?
9. Is the DSS use properly diffused within the institutions/users for which it is intended?
10. Was training provided for use of the DSS model use was provided?
11. Is there a detailed user manual with practical examples demonstrating the usefulness of DSS for solving concrete problems of everyday life of institutions/DSS users?
12. In your opinion, what is the usefulness of the DSS as a tool?
13. In your opinion, what are the main benefits of the DSS (specify indicators: average processing time for cases, number of water permits awarded etc.)?
14. What are the main problems / shortcomings of the DSS?

Model effectiveness:

15. Did the availability of the model (a) enhance your understanding of the system or (b) help advance your agenda?

16. Did you use [any of DSS] model or did [name of consulting/research group] use it on your behalf? (Describe to interviewee what the term "use" here is intended to mean running the model and interpreting results)
17. Did the DSS help drive or inform the decisions?
18. Was the interactive negotiating sessions with the model helpful or a hindrance to the process?
19. In your opinion, did the DSS change any aspect of the negotiations?

Participation Group: Government Agencies

Questions

1. What is the role of the agency on day-to-day bases in the management process?
2. What type of technical support does the agency provide to the water basin committees?
4. How often do basin committees make use of this technical support?

Model accessibility:

5. What was the nature of the agencies participation (When/where/what did it participate in)?
6. Was training provided for use of the DSS model?
7. What are the main benefits of the DSS?
8. What are the main problems / shortcomings of the DSS?

Model effectiveness:

9. Did the availability of the model (a) enhance understanding of the system or (b) help diversify the agenda?
10. Did the DSS help drive or inform the decisions?
11. In your opinion, did the DSS change any aspect of the negotiations?
12. How important are models in a political context?

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The Johns Hopkins University: Baltimore, MD — 2007—Present
Dpt. of Geography and Environmental Engineering Graduate Research Assistant

- Integrated Water Resource Management in Brazil and the role of computer modeling for stakeholder engagement in water allocations (2011-present)
- Food Security: Predict percent undernourishment at the country level based on statistical models that use health, food trade, and climate data as explanatory variables (2009-10)
- Providing sustainable irrigation water for food security and poverty alleviation in HIV/AIDS affected areas (2008)
- Economic Measures and Quality of Life Indicators Related to Health; a historical Geographic Information System (GIS) research study of Baltimore, MD (2007-09)

PUBLICATIONS

Falconi, S.M. and Palmer R.N., An interdisciplinary framework for participatory modeling design and evaluation What makes models effective participatory decision tools? Water Resources Research, 2017. doi:10.1002/2016WR019373

Shortridge, J.; Falconi, S.M.; Guikema, S.D.; Zaitchik, B., Climate, agriculture, and hunger: Statistical Prediction of Undernourishment Using Non-Linear Regression and Data Mining Techniques. Journal of Applied Statistics, 2015. 42(11): 2367-2390.

Shortridge, J.; Falconi, S.M.; Guikema, S.D.; Zaitchik, B., Signs of Hunger. Significance, 2015. 12(5): 28-31.

Manca, R.; Falconi, S.M.; Zuffo, A.C.; Dalfre, J.G., Contributions to Increase the Availability of Water Supply in Regions of Water Shortage-The Case Study of São Paulo, Brazil. Wessex Institute of Technology Transactions on Ecology and the Environment Conference Proceedings, 2014. 191(2): 1567-1579.

Francis, R.A.; Falconi, S.M.; Nateghi, R.; Guikema, S.D., Probabilistic Life Cycle Analysis Model For Evaluating Electric Power Infrastructure Risk Mitigation Investments. Climatic Change, 2011. 106(1): 31-55.

Falconi, S.M., Challenges Beyond Engineering: Lessons from KwaZulu-Natal South Africa. Global Water Program Magazine, 2010.

SELECTED PRESENTATIONS

"State of São Paulo's Water System" **Fernand Braudel Institute of World Economics,** Aug 25, 2015.

"Drought Preparedness and Virtual Drought Exercises " **Water Sustainability Forum,** UNICAMP, Mar 17-18, 2015.

"Shared Vision Planning and Model for the Cantareira System" **International Workshop on Conflict Resolution and Water Scarcity in the State of São Paulo***,* UNICAMP, May 15, 2014.

"Chronicles of a Crisis Foretold: Is Collaboration Possible in São Paulo" **U.S. Department of State**, Nov 5, 2014.

"New Ideas are the Currency of Science" **SEED First National Teacher Conference** in Quito, Ecuador, Nov 16, 2012.

"Ram Pump Irrigation Systems in KwaZulu Natal, South Africa: Impacts on Food Security, Health and Subsistence Agriculture" **The Johns Hopkins University, School of Advanced International Studies**, joined presentation with Dr. Sharon Nappier, Apr. 2008.

"Two Faces of Ecuador; Natural Wealth and Human Poverty" **Columbia University-Earth Institute**, Apr 2007.

MEDIA COVERAGE

"Failures in water governance aggravate the water crisis, specialist point out." Journal UNICAMP, Issue 623, Mar 23, 2015.

"President of ANA advocates for openness for revising the Cantareira permit allocations." Globo News, Mar 19, 2015.

"Conflict and inefficient planning in water crisis." UNICAMP News, Mar 19, 2015.

"Researchers debate at UNICAMP the use of Cantareira's dead storage." Globo News, May 15, 2014.

"In search of Hydrosolidarity." UNICAMP News, May 15, 2014.

EXTRACURRICULAR

Languages: Spanish (Native), English (Proficient), Portuguese (Proficient)
Johns Hopkins Cycling team (2008-2010)
The Nations Triathlon, Olympic distance (2009, 2010)